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Long-term Monitoring of Soil Erosion and Soil and Water Conservation in Afdeyu, Eritrea (1984 – 1998)

Soil Erosion and Soil and Water Conservation Database

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Preface

Increasingly alarmed by the seriousness of land degradation in the Eastern African highlands and encouraged by efforts undertaken by the concerned governments to conserve soils and water for agricultural purposes, scientists and development specialists created the Soil Conservation Research Programme (SCRP) in 1981. Their aim was to contribute to the technical, ecological, economic and social improvement of conservation efforts. The SCRP was carried out with the support of the Swiss Agency for Development and Cooperation (SDC) in a series of programme phases that lasted from 1981 to 1998.

The Soil Conservation Research Programme (SCRP) was established as a network of seven research sites in different agro-ecological belts, one of which is Afdeyu in the tef-growing semi-arid environment of the Eritrean highlands north of Asmara. From 1984 to 1992 the data collected at Afdeyu station were compiled and analysed together with those of other research sites. After Eritrea's independence, the responsibility for the station was taken over by the Ministry of Agriculture in Asmara, and in 1998 also the donor agency changed from the SDC to the Syngenta Foundation.

Activities started in 1984 when a permanent station was established and resident staff was appointed. A modest infrastructure was set up, e.g. for runoff and erosion monitoring, soil conservation experimentation, monitoring of land use and production, soil surveys, and appraisals of land degradation. Resident research assistants collected such data as for example river sediment samples every 10 minutes during all rainfall events, day and night, season after season, and year after year. Laboratory analyses were conducted, data were compiled and encoded, maps were digitised. Then the data were analysed and included in a detailed database. The present summary report is one of the many possible outputs.

In 1984 when research work was initiated the 177 ha catchment already had a considerable portion of its cultivation land conserved. Traditional, old bench terraces on the lower slopes served as water conserving technology. These had been supplemented in the early 1980s by level stone bunds on steeper cultivation land more uphill, although consisting of low-quality structures. Upgrading works and a more intensive soil conservation campaign took again place in early 1986 while the Afdeyu dam was being constructed. These measures, however, were only moderately efficient due to a lack of systematic maintenance. After a series of years without much soil conservation activity, an intensive campaign was again launched in 1998, consisting of large soil and stone bunds with two parallel ditches immediately above and below each bund. To date, about 80 % of the catchment can be considered as treated with efficient measures, while the remaining portion of 20 % is either flat land or rocky. For the monitoring and interpretation of catchment runoff and sediment loss, the above history of soil and water conservation will be important.

The present document focuses on the overall approach and methodology of the programme and its resulting database. In addition, it refers to a number of supplementary studies - published elsewhere - that were carried out by BSc and MSc students, as well as by consultants and experts. The database report is therefore not the sole output of research. But it can constitute a useful source of general information for further analysis, synthesis, and interpretation in view of development recommendations and technical proposals; it may also stimulate further research.

The first part (Part I) of the document describes the overall SCRP approach and methodology. The second part (Part II) offers an overview and a general analysis of the data collected.

Most important, however, is the interpretation of these data. Afdeyu results have been used by specialists such as soil conservation experts, agricultural extensionists, and other stakeholders such as policy-makers or university teachers and students. International consultants, donors, evaluation teams, and researchers working in similar problem settings and environments also widely used the data.

The station now has 17 years of record – a source of high value for all those concerned with soil and water conservation in Eritrea. I would like to thank every individual who contributed to making such a long record possible – by making either direct or indirect contributions. Personally, as the initiator and first director of the SCRP from 1981 to 1987 and the person responsible for the programme at CDE thereafter, I am deeply indebted especially to the technical field staff of the station, Daniel Medhanie and Semere Asmelash, who have run the station with great dedication and personal commitment. Without their efforts, the successful running and management of Afdeyu would never have been possible.

Berne, December 2001

Hans Hurni

Table of Contents

Illustrations

Tables

Abbreviations, Acronyms, Explanation of Terms

a.m.:	before 12 at noon	
ACED:	Assessment of Current Erosion Damage	
Crops:	bl	barley
	bn	bean
	fa	fallow
	hb	haricot bean
	ho	horse bean
	li	linseed
	mz	maize
	on	onion
	po	potato
	te	teff
	wt	wheat
Cs:	Sediment concentration [g/l]	
CV:	Coefficient of variation $\frac{\mathrm{SD}}{\mathrm{Mean}}$	
CV %:	CV x 100	
DARHRD:	Department of Agricultural Research and Human Resources Development, Ministry of Agriculture	
E:	Kinetic energy of rainfall: 11.89 + 8.73 log10 I	
EI30:	Rainfall erosivity [J/mh]	
EP:	Experimental plot; 6 x 30 m	
Eros:	Erosivity [J/mh]	
GIS:	Geographic Information System	
GPS:	Geographic Positioning System	
HH:	Household	
I:	Intensity of rainfall	
m asl:	meter above sea level	
Max:	Maximum	
Mean Dev:	Mean Deviation $\sum_{i=1}^{n} \frac{\lvert x_i - \bar{x} \rvert}{n}$	
Mean:	Arithmetic mean $\frac{\sum_{i=1}^{n} x_i}{n}$	
Min:	Minimum	
MoA:	Ministry of Agriculture, Government of Eritrea	

MP:	Micro plot; 1 x 3 m
N:	Number of samples
No sel. HH:	Number of selected households
p.m.:	after 12 at noon
PA:	Peasant association
Prec:	Precipitation [mm]
Q:	Discharge [l/s]
Qs:	Sediment rate [t]
Qv:	Discharge volume [m^3]
Rel Dev:	Relative Deviation $\frac{MeanDev}{Mean}$
Ruof:	Runoff [mm]
SCRP:	Soil Conservation Research Programme
SD:	Standard Deviation $\sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n}}$
Solo:	Soil loss [t/ha]
SWC:	Soil and Water Conservation
TP:	Test plot; 2 x 15 m
xx:	Abbreviation of station name. Af = Afdeyu
yy:	Abbreviation of year

Summary

Afdeyu is one of 7 research stations of the Soil Conservation Research Programme (SCRP), which were established in the early 80ies in different agro-climatic belts of the East African highlands. It is located some 20 km north-east of Asmara, in the Maekel zoba, Serejeka sub-zoba, about 2 km east of the road from Asmara to Keren. Altitudinal range of the catchment is 2300 - 2460 m asl and the catchment size is 177 ha.

The background information presented in Part I is meant to support adequate understanding and interpretation of the data and explanations which follow in Part II. In Part I, Chapter 1 highlights the problem-oriented character of the SCRP, its objectives, institutional affiliations and the potential user groups for its outputs and products. Chapter 2 describes the basic concept and methodology of the research programme, such as the selection of sites in different agro-ecological zones, the different research levels and the integration of records. Chapter 3 focuses on the adaptation of programme activities to the research needs, which have changed over time as attempts were made to incorporate relevant new research ideas as well as to respond to famine and political change. Chapter 4 critically reviews what has been achieved, but it also stresses the constraints that prevented the programme from meeting some of its aims. Chapter 5 presents the research and observation methods in greater detail. Finally, Chapter 6 provides examples of the management and interpretation of data.

Part two of the report presents an overview of data, collected to understand soil erosion processes. Data collection focused on the universal soil loss equation. Part two presents monthly and annual sums or means. For more detailed information on different topics, further references are listed at the end of each chapter.

According to the agro-climatic classification of Eritrea, the catchment is located in the *Kebesa* zone, also known as dry *Weyna Dega*. The climatic conditions are semi-arid, mean daily air temperature is about 17 °C, and mean annual rainfall about 450 mm. High variability of rainfalls and erratic heavy rainfalls of short duration and high intensity are typical.

Soils of the catchment are mainly Cambisols with a loamy texture, developed on metamorphic volcanic material of Proterozoic age. High land use pressure and a deficit in fertiliser led to nutrient impoverishment during the long time of land use. Erosion through water reduced soil depth and subsequently also soil fertility.

Rainfed subsistence-oriented mixed-farming with ox-drawn ploughing and livestock-keeping is the traditional as well as the actual farming system. Main crops are barley and wheat, covering about 60 % of the total arable land. Small areas along the river bed are used for irrigation farming to produce onions, tomatoes and potatoes.

Demographic data show that land use pressure in the area is very high. Eight persons per ha of cultivated land were counted in 1999. This is also reflected in the results of

a wealth ranking: more than half of the population was ranked to the poorest category in 1999.

During the past 14 years, soil erosion processes were monitored on different plots. The plot set up, established in 1984 (experimental plots in 1988) was as follows:

2 micro-plots, 1 x 3 m on a slope of 2 % and 10 % respectively

4 test plots, 2 x 15 m under the following conditions:

- Test plot 1: 31 % slope, covered with grass
- Test plot 2: 2 % slope, covered with different annual crops
- Test plot 3: 10 % slope, covered with different annual crops
- Test plot 4: 65 % slope, covered with rock, grass and bare soil

4 experimental plots, 6 x 30 m on a slope of 31 %:

- Control plot with no conservation structures (regular farming)
- Experimental plot with level double ditch
- Experimental plot with level Fanya Juu
- Experimental plot with level bunds

The different plot categories allow the monitoring of a combination of different erosion processes, such as splash erosion on micro-plots, splash-, sheet-, and prerill erosion (and to a small extent, resedimentation) on test plots, and splash-, sheet-, prerill- and rill erosion on experimental plots. Besides the factors controlled by the measurement set-up such as slope length, slope inclination, exposition, crop type, soil type, other parameters, such as vegetation cover, soil cover at the time of heavy rainfall, interception under trees (on experimental plots) soil moisture content, soil infiltration rate etc. influence the amount of soil loss and runoff from plots.

A comparison of micro-plot and test plot results shows that the mean total amount of soil loss from micro-plots is almost twice the mean total amount of soil loss from the comparable test plot. The high amount of soil loss from micro-plots represents the maximum erosion, without resedimentation or other accumulation processes and is much higher than on test plots.

Plots reflect areal erosion. Analysis of all plots shows that annual totals or monthly means do not reflect the full dynamics of erosion processes. Analysis of test plot data on storm basis show, that large amounts of soil loss occur during only a few rainfall events. To study where the "erosion-hot-spots" are and what amount of soil can be eroded during one single rainfall event, direct observations and the mapping of affected areas are recommended.

The main purpose of the experimental plots was to study the effect of different soil conservation measures on soil loss and runoff. Different level structures were tested because, besides protection against soil erosion, also water harvesting is a demand in Afdeyu. For soil loss reduction, the most effective measures from a technical point are level *Fanya Juu* and level double ditch. Both measures are also the most effective to reduce runoff and harvest water, level *Fanya Juu* in general a bit better than level double ditch. Taking into consideration that all measures occupy a considerable percentage of the field (17 – 24 %), the technologies need to be further optimised before being recommended on-farm.

Part 1

Concept and Methodology

Problem-oriented Soil Conservation Research

From its inception in 1981, the Soil Conservation Research Programme (SCRP) was mainly problem-oriented. By that time, many SWC technologies were applied too rigidly. The need to assess their efficiency and elaborate possibilities for improvement were major reasons why the Swiss Agency for Development and Cooperation helped establish a research network through the University of Berne. The main objective of the SCRP was to support soil conservation efforts by monitoring soil erosion and relevant factors of influence, by developing appropriate soil and water conservation measures, and by building local and international capacity in this field of research. It was stated at an early stage that "the SCRP should confine itself to the evaluation of data most urgently needed, whereas a wider and more detailed investigation should be aimed at in the future" (Hurni 1982).

While the ultimate target group of soil conservation information are land users, the direct user groups of SCRP research results, database, and publications are the following circles:

- soil conservation experts, planners and decision-makers at the regional / national level. They prepare the general framework for a more sustainable land management by improving land policies, allocating extension services, designing incentive programmes, and improving training and education facilities and programmes.
- agricultural extension services and development agents at the local or community level, who support land users in their efforts to develop appropriate land management practices.
- researchers who contribute to work in the field of soil and water conservation and management.

From the beginning of the activities in Afdeyu (1984), the programme attempted to respond to needs felt at the time, for example the development of soil and water conservation (SWC) technologies which are technically feasible, ecologically sound, economically viable and socially acceptable. Today it is clear that research on its own could not work out truly innovative solutions for the overwhelming problems of land degradation in the Eritrean highlands. In order to achieve this, a strong collaboration between researchers, extension services and, last but not least, the land users themselves is required. By now, it is also understood that best results can only be achieved through an iterative process, which includes approaches such as participatory technology development (PTD), from the stage of designing to the stages of implementing, monitoring and improving SWC measures. For many reasons, it was not always possible in the past to guarantee this form of co-operation; such a task still remains a challenge even today. Thus, the programme alone has certainly not been in a position to come up with *the* standard solution for putting an end to soil degradation in the Eritrean highlands. But those involved in the programme have gained considerable methodological experience and have produced a wealth of data that have been used by researchers, consultants, experts, planners and decision-makers, providing substantial information for their specific tasks on the difficult path towards more sustainable land management.

Data generated by the programme since 1984 encompass a wealth of information, of which only a fraction has been utilised so far. The data of the seven SCRP research stations together probably form one of the most extensive and comprehensive databases in Sub-Saharan Africa to date. It is hoped that many more researchers and experts will make use of this wealth of data, and that it will also provide the starting point for efforts to formulate and conduct complementary programmes in the future.

Concept and Methodology

The research concept of the SCRP has been described in detail by Grunder (1988), Hurni (1989 and 1994), Herweg & Grunder (1991), and Herweg & Hurni (1993). It involved the selection of benchmark sites with various socio-cultural settings in several different agro-ecological belts of the Eritrean and Ethiopian highlands (Table 1). Accordingly, test catchments with traditional land use systems and a size between one and seven km^2 were chosen. Soil erosion and other related variables were monitored in these catchments. The sites were first observed without SWC for a period of one or more years, and then monitored for several years once SWC measures had been implemented.

The programme was implemented with as little disturbance of the catchments and the farmers' fields as possible; all experiments were on-farm instead of on-station. The programme mainly monitored runoff / river discharge and soil loss / sediment yield at different scales, on different slopes and soils, under various land uses and crops, and under several SWC treatments. At the same time, climatic data such as amount, erosivity, intensity, inclination and direction of rainfall, air and soil surface temperature, wind direction, evaporation and duration of sunshine were recorded in order to interpret the erosion measurements. Land use was mapped for each cropping season. Throughout the catchment, crop yield and biomass samples were collected to monitor the production of the major crops. *Current soil erosion* was measured on test plots and at the hydrometric station, where hundreds of events were recorded over the years on each site. This allowed the determination of the *average patterns of soil erosion*, for example by calculating mean annual and monthly results. *Extreme patterns of erosion* were determined by analysing the impact of the most severe rainstorms (critical times). In most stations, erosion rill mapping was undertaken right after such extreme erosion periods revealed the critical locations of soil erosion. Rill mapping has not yet been carried out at Afdeyu but is strongly recommended.

Table 1: SCRP benchmark sites in different agro-ecological belts

Agroecological belt	Research site	Altitude [m asl]	Major crops
Weyna Dega	Afdeyu / Eritrea	2430 – 2520	wheat and barley, pulses, lentils, maize
Weyna Dega	Anjeni / Gojam	2407 – 2507	tef, wheat
Weyna Dega	Hunde Lafto / Harerge	1963 – 2315	sorghum, maize pulses
Weyna Dega	Gununo / Sidamo	1982 – 2103	tef, maize, wheat, pulses
Weyna Dega	Dizi / Ilubabor	1565 – 1789	maize, tef
Dega	Maybar / Wello	2530 – 2858	wheat, barley, pulses
High Dega	Andit Tid / Shewa	3040 – 3548	barley

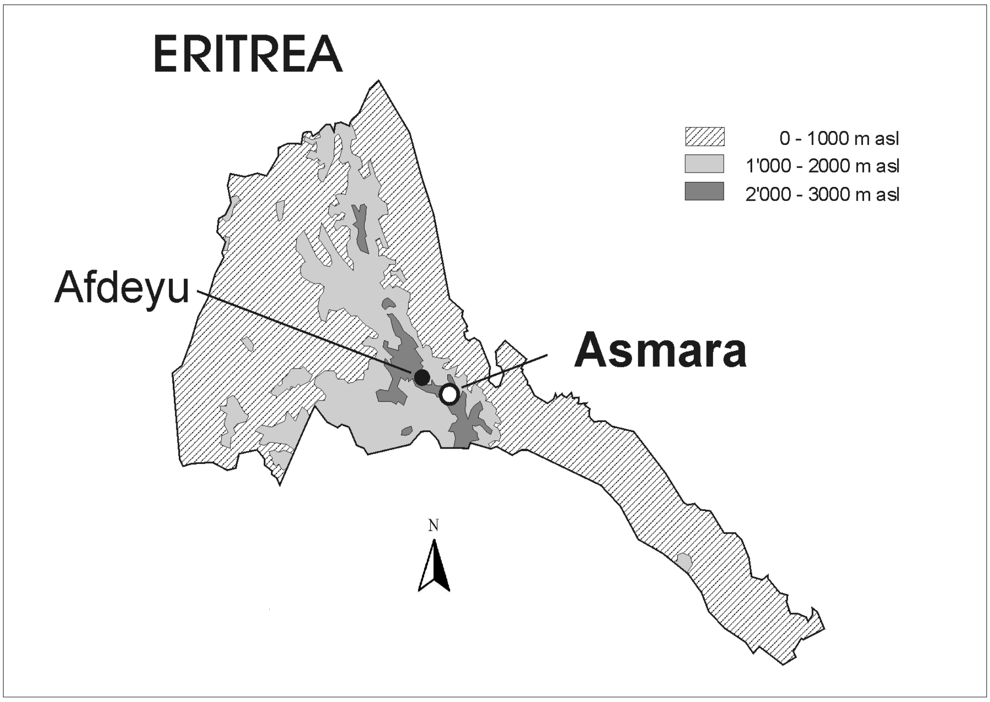


Figure 1: Map of Afdeyu research site

In addition to the standard programme described above, site-specific research needs were met with a supplementary programme. Population and livestock dynamics, household land management strategies, attitudes towards, and perceptions of, SWC, as well as reactions to policy changes were documented specifically. BSc, MSc, PhD and short-term studies covered other relevant topics, such as agronomic SWC measures, indigenous SWC measures and strategies, soil fertility, erosion modelling, environmental education, and many more. The programme used a hierarchy with different research levels (Figure 2). At levels 3, 4 and 5, data were collected exclusively by the programme itself within the seven research catchments and their surroundings. At levels 1 and 2, programme data could be combined with information from other sources such as mapping, meteorological or land use planning authorities.

– Examples of outputs at the national and regional / zonal levels (levels 1 & 2) are products such as maps of altitudinal zones and land use at a scale of 1:1'000'000, or studies of rainfall erosivity. Climatic, land use/land cover, geomorphologic, erosion, and demographic information can be provided in a digital form as part of a Geographical Information System (GIS).

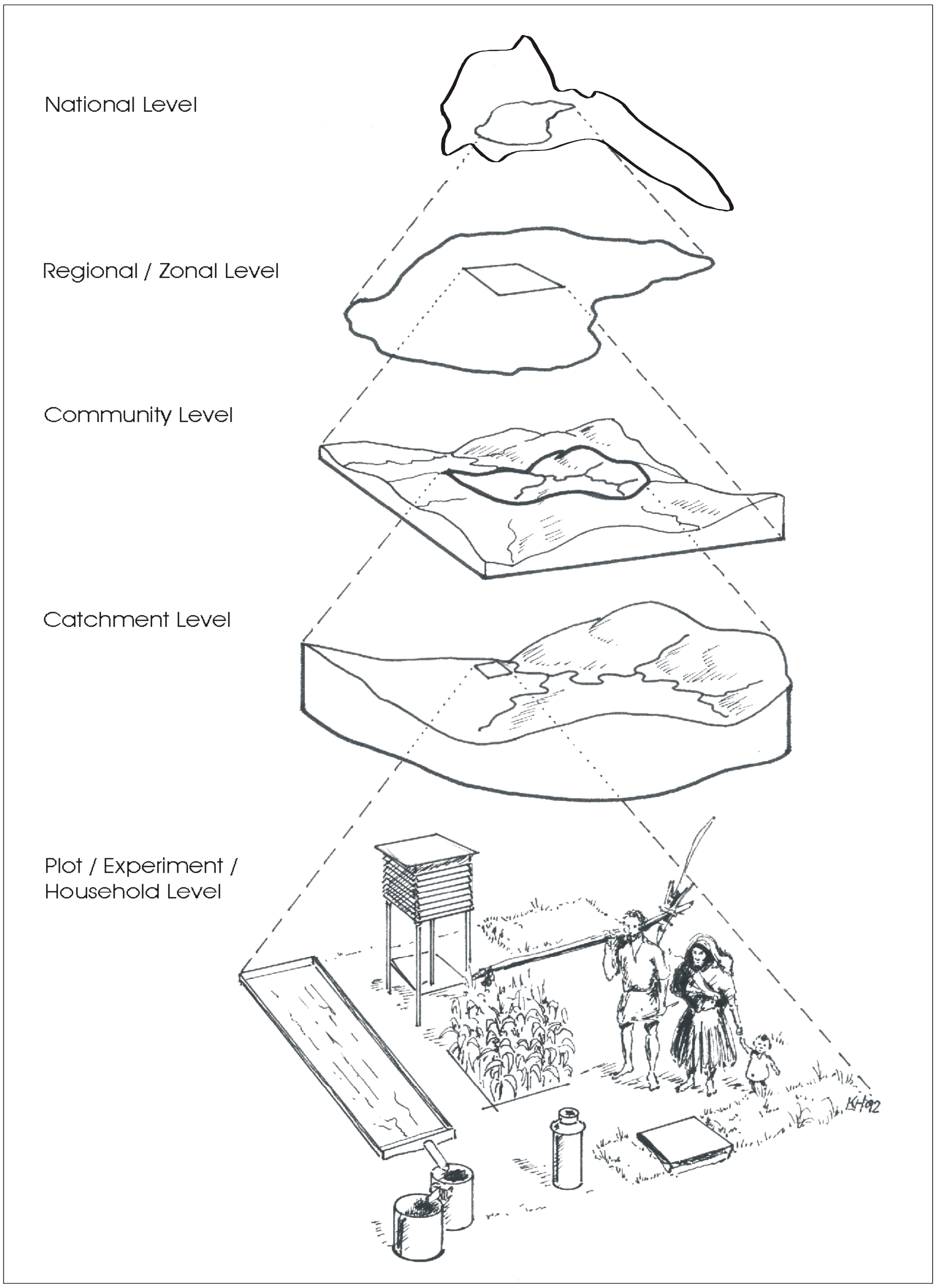


Figure 2: SCRP research levels (Herweg & Hurni 1993)

- Outputs at the *intermediate / community* level (level 3) comprise e.g. topographic maps, soil maps, and demographic data. More detailed surveys could be conducted to assess farmers' perceptions of the environment, to study their response to environmental problems, and to determine social, economic, cultural and political limitations to SWC.
- At the *catchment* level (level 4), the SCRP monitored river discharge and sediment yield as well as land use, different parameters of vegetation, and crop production. Spatial patterns and immediate causes of soil erosion could be documented after several erosive rainstorms (assessment of current erosion damage: ACED).
- Climatic data were recorded at the *plot / experiment / household* level (level 5). The impact on soil erosion and production of land use, vegetation, slope gradient, soils, SWC measures and various agronomic parameters was measured on test plots, micro-plots and experimental plots. Socio-economic aspects such as land users' SWC strategies and the range of technical options available to them were investigated at the household level.

Adaptations of the Research Programme

The research methodology described so far can be considered the standard programme. However, changing biophysical and socio-economic settings as well as changing research needs have required a more flexible response and adaptations of the research set-up.

- In view of a wider application of data and information from both the SCRP and other sources, a Geographical Information System (GIS) was introduced. A digital terrain model based on 200 m contour lines was systematically developed and now allows the modelling of soil erosion and the relative importance of soil degradation and declining agricultural production in the highlands (Hurni 1993). Of course, such models and scenarios must be refined and upgraded permanently.
- Farmers typically react in many different ways to the establishment of SWC measures, for example, by "removing" SWC structures introduced during campaigns. There is an on-going debate whether this should be considered a form of farmers' destroying or of adapting SWC measures. This calls for more detailed socio-economic research and studies of indigenous SWC practices.
- Starting from 1988, SWC measures were tested on large (experimental) plots (180m^2). These experiments allowed to compare different measures and offered an interesting insight into their impact on soil erosion and production. Eventually, the results began to shed some light on the detrimental effects of inappropriate SWC (Herweg & Ludi 1999).
- The planned development of a small dam at Afdeyu for the supply of water for domestic use, watering livestock, and irrigation provides yet another opportunity to make use of the database of the programme. To determine dimensions and life span of the dam, especially runoff and sedimentation records prove highly relevant.

These examples highlight the evolutionary and applied character of the research programme. Flexibility needs to be also built into the planning process, i.e. by the move to involve Eritrean institutions concerned with research and soil conservation more intensively. The programme always tried to follow a dual strategy. On the one hand, it maintained a standard programme in order to obtain long-term data series for a better understanding of the long-term characters of soil erosion, soil conservation, and their impacts. On the other hand, its supplementary activities introduced the necessary flexibility to take into account additional and site-specific research needs, which it did, for example, by way of BSc, MSc and PhD studies.

A Critical Evaluation of Major Achievements and Constraints

Based on two external evaluations in 1993 and 1998, the following statements can be made:

- The SCRP has compiled a wealth of first-hand data on the above-mentioned topics; this is unique in the African context. However, as of yet, it has only been possible to analyse and synthesise the basic data, for example on an annual, seasonal and monthly basis. Much more needs to be done; e.g. the investigation of data on single rainstorm periods has only just begun (Herweg & Stillhardt 1999). In addition, the application of data to wider areas and the prediction of the potential performance of SWC measures (before implementation) require the development of an appropriate soil erosion model.
- The use of research findings for practical application can be prepared in many ways. Up to now, results and interpretations have been compiled for the extension services in the form of field manuals on soil conservation (Hurni 1986), erosion damage assessment (Herweg 1996), photo-monitoring (Bosshart 1997), indigenous knowledge and participatory technology development (Yohannes and Herweg, 2000). The use of some of these products and the development of further practical tools need to be supported by regular training and updating. These manuals are only one of the many potential practical applications of the research results.
- Because of the tremendous rates of soil loss measured and the fact that biological SWC has a rather limited effect at the beginning of the rainy seasons, the SCRP has always focused on physical (mechanical) SWC measures. A future challenge will be to carry out experiments which include agronomic and biological SWC measures. Unlike physical measures, which can be tested with standard experiments throughout all agro-ecological zones, biological SWC research differs considerably from site to site.
- The same holds true for research on the socio-economic aspects of SWC at the local level of the benchmark sites, which also requires a highly site-specific approach and methodology. Beyond that, the SCRP is not given the mandate to adequately address the political and economic framework for SWC at the national and regional levels, i.e. such aspects as SWC legislation, incentives and subsidies, land security, and other highly important issues.

Methods of Measurement and Observation

in order to be able to properly interpret the data presented, it is essential to have some knowledge about the methods, equipment and procedures that were, and still are, used in Afdeyu.

Specific points to be considered when using SCRP data

In general, all data should be carefully interpreted, because each method has its specific range of application.

Spatial and temporal replication: In the rugged highland topography SWC measures could not be tested with spatial replication on experimental plots (EP), because it was impossible to find a larger number of plots with the same slope gradient, soil properties, and farm operations. The data reveal that all SWC measures tested on EPs performed “better” than the control plot with respect to soil loss reduction. Without spatial replication, these data are indicative, the statistical significance of a “best” measure cannot be determined! Instead SWC measures were tested with temporal replication, i.e. by monitoring a great number of storms. Thanks to this, it was possible to assess the advantages or disadvantages of one measure in comparison to another with a certain degree of reliability (Herweg & Ludi 1999). In addition, soil erosion is monitored at different levels of measurement (“triangulation”).

Range of application: application of data beyond their specific range is therefore most problematical. It may lead to severe misinterpretation and wrong conclusions. Such a misuse of data may lead to yet another burden – but will impact on the land users, not the scientists! Therefore, users of the data are kindly requested to contact the specialists in the case that it is unclear whether or not a specific interpretation is appropriate or not.

Climate

Temperature was recorded on a daily basis by reading minimum and maximum thermometers at a height of 2 m (air temperature, Stevenson screen) and 5 cm above the soil surface (surface temperature, under shelter). Evaporation was measured with a Piche evaporimeter (ml) at a height of 2 m (Stevenson screen) twice a day at 8 a.m. and 6 p.m. Wind direction and strength were estimated at a height of 1m twice a day at 8 a.m. and 6 p.m. with a simple thread fixed on a nail located in the centre of a compass grid. The wind direction was recorded from the compass grid. The wind speed or velocity was recorded as:

weak or **medium** wind (equivalent to a speed of 0-3 m/s) when no movement or only slight movement of leaves was observed;

strong or **very strong** wind (3 - 9 m/s) when movement of branches was observed;

storm (9 - 18 m/s) when breaking of small branches of trees was observed.

A Campbell-Stokes recorder was used to determine the duration of sunshine. It was moved from one station to the next and installed for at last one year in each station.

Rainfall data were collected with a pluviometer (Lamprecht type 1509-20) at 1-1.5 m above the ground, and with a rainfall inclinometer (construction after Hurni 1988) located close to the test plots and the hydrometric station. These instruments were supplemented by daily rain gauges (Hellmann) at two or more locations within each research catchment, to observe differences in the spatial distribution of rainfall. Data collection started with the establishment of the station.

- The pluviometer recorded rainfall with a resolution of 2 cm per hour and 1 cm height per mm of rainfall. On this basis, it was possible to distinguish the high intensity intervals of each rainstorm; this is essential for calculating rainfall erosivity. The amount and intensity of rainfall were directly determined by reading the records (monthly chart rolls), while rainfall energy and erosivity were computed. For each storm interval of similar intensity the energy density E was calculated using the formula $11.89 + 8.73 \log_{10} I$. All energy values E_i of one storm were added ($\sum E_i$) and multiplied by the maximum intensity during 30 minutes (I_{30}), in order to compute the erosivity of this storm (EI_{30} index). The EI_{30} indicates the climatic probability that soil erosion will be caused (Wischmeier & Smith 1978, cited in Krauer 1988).
- Two to four daily rain gauges monitored daily rainfall (mm) at different locations within the research catchments. Farmers living nearby used plastic jars identified for each day of the week to empty the gauges. Measuring and recording were done at weekly intervals by the research assistants. For most of the stations, data on rainfall distribution and spatial variability were recorded starting from 1984.
- The rainfall inclinometer contains four inclined rain gauges in all compass directions (N, S, E, W) to enable computation of the average weighted rainfall direction of each storm. Thus, each storm was represented by a three dimensional vector, representing the mean angle and direction of rainfall on a daily basis (Hurni 1988).

Aridity was defined after De Martonne and Lauer (1951/1952): $I = 12N/(t+10)$. During arid months, I is lower than, or equal to, a value of 20 (N: sum of monthly rainfall; t = mean monthly temperature).

Land Use and Crop Production

Land Use / Land Cover

The dynamics of land use and the approximate agricultural production within the research catchments were derived from seasonal land use mapping and harvest yield measurements. The methods applied for the collection of land use data were primarily determined by the technical possibilities available. Seasonal land use was mapped on sketch maps, which comprised four steps:

- mapping of the most important elements, such as field borders on areas with intensive cultivation, fallow land, and the different soil covers on pasture. Forest and bush cover were taken over from topographic maps (1982 – 1988). All graphic mapping elements were drawn from the perspective of opposing slopes;
- creation of a set of captions with information about the various types of land use (mixed or alternate use), crop types and varieties;
- two different methods of area analysis proved effective in practice. In both cases the spatial elements were drawn on tracing paper. In method 1, millimetre tracing paper was used to count the total squares for each land use type. The multiplication by the map's scale gave the approximate size of the real area. In method 2, the areas on the tracing paper were cut out and weighed on a precise laboratory balance to determine the percentage of individual land uses in relation to the total area.

The initial maps were not suitable for the determination of the exact location and size of a specific area. Thus, detailed analyses of the land use dynamics of a given location were of low reliability. For all stations, overlaying maps from several years showed that the geometrical differences between mapped elements could be explained neither by the generally high level of pressure on the land nor by climatic variations. Instead, the problem was the inaccuracy of the data collected. Examining the case of Andit Tid, Stuber (1998) showed that the collection method was not suitable for numerical analysis over several years. Thus, the need arises to improve data collection and land use mapping.

In the course of an evaluation of various new methods of data collection, Krauer (1994) showed that the GPS (global positioning system) delivered insufficiently precise results if the field size was very small. GPS can be used either if at least two GPS units are available (post-processing), or if the differential method is used and in such cases provides sufficiently precise base line data for land use studies. The use of high resolution remote sensing data would have been unreasonably expensive, and would have required substantial labour and training inputs. But because the SCRP did not give high priority to the determination of land use dynamics, remote sensing was not taken into consideration.

A high quality base map and an excellent satellite image (Ikonos satellite image with a resolution of 1 m) were created for land use monitoring in the Afdeyu research area. With the help of these base maps, land allocation maps can be developed which can then be used for land use mapping. This makes it possible to compare the years inventoried, since land tenure changed less frequently than the crop rotation.

Crop Yield and Biomass Production

Production data (crop yield and biomass production, in t/ha) were collected after each cropping season on all major crops produced in the research catchments. Samples were taken on all runoff plots (harvesting the whole plot area) and on farmers' fields (harvesting a defined area of 4 to 9 m^2). When the crop was ready for harvest, it was cut and collected from all sites in the same way as the farmers in the respective catchment did it. All the plants of each sample area were collected, including weeds. But roots and weeds were only included in the calculation if this reflected the local practice. The samples were exposed to the sun for about 20 days, and the grain (including the cover) was separated from the rest by hand. The sundry weights of grain with cover on the one hand, and the straw on the other hand, were recorded. Then, the grain was separated from the cover by hand, and separately weighed and recorded. Finally, the grain and all of the biomass were returned to the respective farmers.

Between 1981 and 1986, sample areas of 9 m^2 (3 m x 3 m) were used. After 1986, the number of harvest samples increased about threefold, as supplementary samples were collected from areas between two conservation structures (above a structure, in between two structures, and below a structure) and the size of sample areas was reduced to 4 m^2 (2m x 2m). As from 1990, almost half the harvest sample areas were permanent (fixed), to allow the monitoring of trends on specific locations. The other half were temporary (non-fixed) sample areas representing average crop stands, in order to obtain a sufficient number of samples for each crop type considered.

Soil Erosion and Soil and Water Conservation

Research on soil erosion and soil and water conservation (SWC) requires a multi-level monitoring approach. Various devices (test plots, hydrometric stations, sediment troughs) or methods (assessment of current erosion damage - ACED) make it possible to examine soil erosion and SWC from different angles. Results gained with these methods eventually need to be interpreted together to get an overall idea of the order of magnitude, as well as of the temporal and spatial dimensions, of soil erosion (cf. Table 2). Basically, the process of soil erosion is the result of the combined impact of a number of factors such as rainfall, erosivity, soil, slope length and gradient, vegetation cover, land management, SWC, etc. The order of magnitude of this process is usually described by four main indicators. These are soil loss and runoff measured on plots, as well as sediment yield and river discharge measured at the hydrometric station. Sediment troughs and ACED (not yet used in Afdeyu) determine soil loss.

Table 2: Methods used for the soil erosion and soil conservation experiments and their indications, limitations and estimated accuracy

Method/ Indicators	Indications (information obtained)	Limitations on the interpretation of results	Accuracy (estimated error ± %)	Remarks and source of information
Hydrometric Station – sediment yield – river discharge	– *areal measurement device*, measuring outflow from a defined catchment; – long-term or permanent monitoring device; – results indicate general performance of on-site land management and possible off-site effects (sedimentation, flood risk, etc.).	no differentiation between sources of erosion within the catchment possible; **Caution:** unreliable extrapolation without knowledge of channel characteristics.	– *sediment yield and river discharge*: – 5 - 10 %	original error was estimated to be 1 - 5%, without considering random errors during measurement (Bosshart 1996, 1997a).
Erosion Plots – soil loss – runoff	– *point measurement devices*, measuring soil transport over a defined slope length (e.g. TP: one average terrace spacing); – long-term or permanent monitoring device; – results indicate soil erosion rates under different soils, slopes, land management practices, SWC technologies, etc.; – results underline the importance of severe rainstorms.	negative balance: considers only soil lost from the area and no deposition gained from upper slopes; narrow plot width encourages entrainment and pre-rill erosion: soil loss rates may be overestimated; **Caution:** unreliable extrapolation without appropriate model.	– soil loss: annual - 3 % storm 6 - 16 % – runoff annual 0.1 % storm 2 - 5 %	accuracy is estimated for erosion plots which are well maintained: e.g. there is no interception of rainfall by canopies of high plants outside the plot; there are no further sinks or sources of sediment and water, etc. inside or outside of the plots (Herweg and Ostrowski 1997).
Sediment Troughs – soil loss	– *areal measurement device*; – results indicate sheet erosion.	malfunction if rills develop near the trough.	– 15 - 20 %	trough catchments above 12 m^2 may involve higher inaccuracy due to limited trough volume.
Assessment of Current Erosion Damage (ACED) – soil loss	– *point-linear measurement*; measuring soil loss at critical locations during severe rainstorms; – short-term monitoring method; – results indicate extreme soil erosion rates.	**Caution**: no extrapolation possible; annual data relatively uncertain.	– soil loss: 15 - 30 %	the accuracy improves with the observers' experience; increasing vegetation cover and more complex rill systems increase error (Herweg 1996).

By monitoring these indicators (variables) over a longer period of time on the SCRP sites, the impact on soil erosion of certain types of land management (on test plots, micro plots) or of SWC measures (on experimental plots) under specific situations (soil type, slope gradient, etc.) was evaluated. On the one hand, plot results generally refer to on-site erosion damage (Herweg and Stillhardt 1999), i.e. where soil erosion took place, and to the performance of protective measures (Herweg and Ludi, 1999). In addition, rill mapping produced information on critical locations on-site

(Herweg and Stillhardt 1999). On the other hand, hydrometric station data indicate the amount of water and sediment that flow out of the respective highland catchment. This hints at the quality of land management including SWC on-site, as well as at potential off-site or downstream effects (Bosshart 1996, 1997a & b, 1998, 1999). The plots and the hydrometric station belonged to the SCRP standard programme. ACED was carried out in most stations depending on the occurrence of rills. Sediment troughs were selectively used in the supplementary programmes in Gununo and Anjeni.

Soil Loss and Surface Runoff

Table 3: Plot type, plot number, dominant land use, soil type and slope angle of all plots in Afdeyu

Test plots (TP)		Micro-plots (MP)		Experimental plots (EP)	
TP 1	Grass Cambisol/Lixisol 31 %			**all**	Fallow Cambisol/Lixisol 31 %
TP 2	Annual crops Cambisol/Lixisol 2 %	**MP 5**	Annual crops Cambisol/Lixisol 2 %		
TP 3	Annual crops Cambisol/Lixisol 10 %	**MP 6**	Annual crops Cambisol/Lixisol 10 %		
TP 4	Rocks, bare soil Cambisol/Lixisol 65 %				

Soil loss and surface runoff were recorded on plots representing different land uses, soil types, slope lengths and gradients, and conservation measures (cf. Table 3). In their vicinity an automatic rainfall recorder (pluviometer) was established which made it possible to link rainfall and runoff measurements. The SCRP standard programme in Afdeyu involved 3 plot types:

- 4 Test plots (TP), 30 m^2 (2 x 15 m)
- 2 Micro plots (MP), 3 m^2 (1 x 3 m)
- 4 Experimental plots or soil conservation plots (EP): 180 m^2 (6 x 30 m) (EPs are described in section “Soil Conservation and Water Management”)

Corrugated iron borders defined the area under consideration for the measurement. They were inserted 10 cm into the ground and their height above surface was about 20 cm. Runoff and soil loss were collected in two tanks at the lower end of the plot through an inlet tube. The first tank (A) accommodated most of the sediment lost from the plot. Through a slot divisor the second tank (B) took 1/10 of the possible overflow from the first tank (A). Activities related to the monitoring of test and micro plots were operated by the research assistants. In order to very closely approximate the prevailing conditions in the catchment, resident farmers determined all agricultural activities on the plots. To facilitate farmers' activities, plot borders could be removed whenever necessary and put back afterwards.

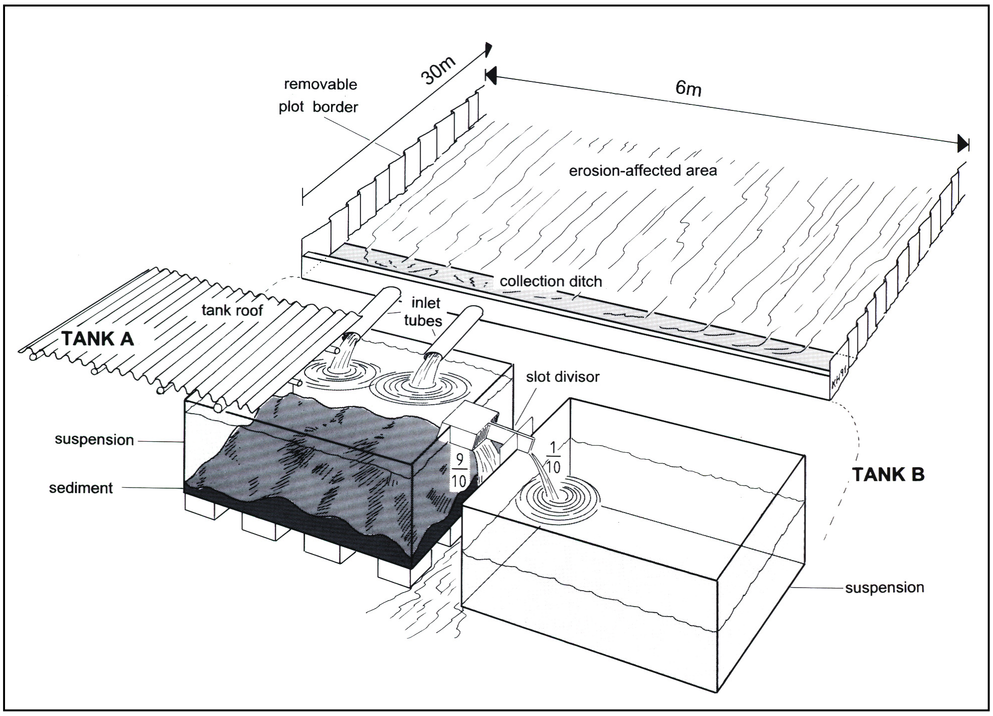


Figure 3: SCRP erosion plot set-up (Herweg and Ostrowski 1997)

Runoff and soil loss were measured (= plots were emptied) when rainfall exceeded 12.5 mm, or when there was more than 20 cm of runoff water in the collection tanks. Thus, it was not possible to collect runoff and soil loss for each storm. Instead, data was collected on storm periods that comprised one to four single storms. To determine the total runoff, the water volume was directly measured in the two tanks. Determining soil loss comprised weighing the bulk sediment mass in tank A, taking a representative suspension sample from tank B, and estimating the amount of suspension in tank A (water in tank A was not stirred, because this would have disturbed the sediment at the bottom of the tank). The suspension sample was filtered and dried in the station. The air-dry suspension sample and a representative sediment sample from tank A were taken for laboratory analysis and determination of soil loss. SCRP (1984) and Herweg, K. & Ostrowski, M.W. (1997) provide detailed information on the measurement procedure, error estimation and accuracy.

Sediment Yield and River Discharge

Sediment yield and river discharge were recorded at the outlet point of each research catchment using a hydrometric gauging station (limnigraph, type Ott R16). At an artificial cross-section (concrete steps) the automatic river gauge recorded the changes in the height of the water level during the discharge periods. The chartrolls had a resolution of 10 minute intervals. The water level served as the basis for calculating the volume of discharge, once a stage -discharge relation was established. The following methods and devices were used to determine the stage - discharge relations: current meter, salt dilution, dye dilution, and dipping bar. During every storm when the water was considered brown, 1-litre samples were taken at 10 minute intervals. When the colour of the water gradually changed from brown to clear, the frequency of sampling was reduced to 30-minute or one-hour intervals. The 1-litre samples were filtered and prepared for further laboratory analysis. Bosshart (1996 & 1997a) provides detailed information on the measurement of river discharge and sediment yield, including the determination of the stage - discharge relations.

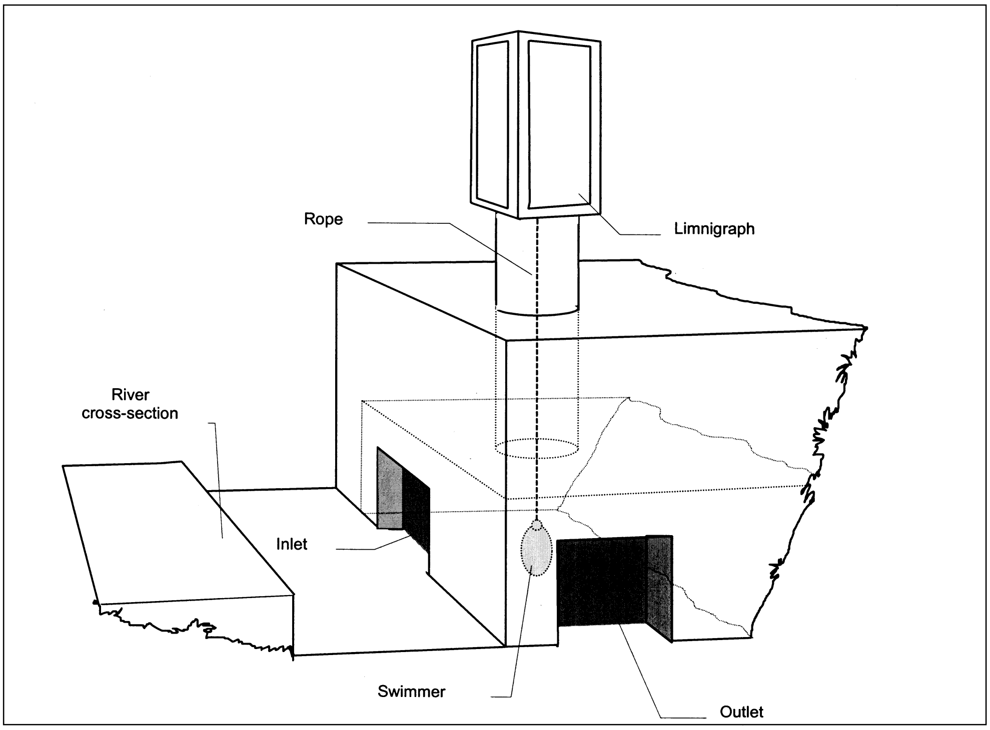


Figure 4: Stilling well at an SCRP hydrometric station (Bosshart 1996)

Soil Movement at Critical Locations

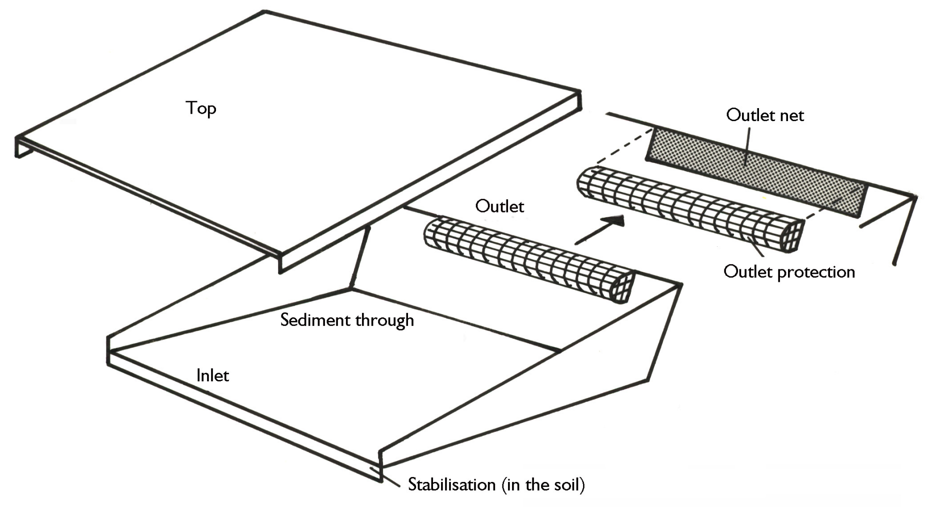


Figure 5: Sediment trough (sketch: Herweg)

To pursue a series of research questions, it was necessary in some cases – and it may also be necessary at Afdeyu in the future - to obtain additional field information on soil erosion, for example at locations in the catchment where there were no permanent devices such as plots and gauging stations. In such cases, the programme used sediment troughs and the assessment of current erosion damage (ACED). Since these two methods do not belong to the standard programme, the data collected and the results are not included in this database report but are discussed in separate publications (Herweg 1996; Herweg & Stillhardt, 1999; von Gunten 1993; Million Alemayehu 1992; Thomas Tolcha 1991; Berhanu Fantew 1991).

The sediment trough measurements take only sheet erosion into account. The troughs in use had a volume of approximately 120 litres (Figure 5). They were dug in the ground and could accommodate sediment originating from smallest catchments of 1 - 12 m^2. But they were not sufficient to accommodate soil loss from rill erosion. Due to the small volume of the trough, runoff was not monitored but drained through a filter at the back of the trough. The troughs were preferably emptied after every storm.

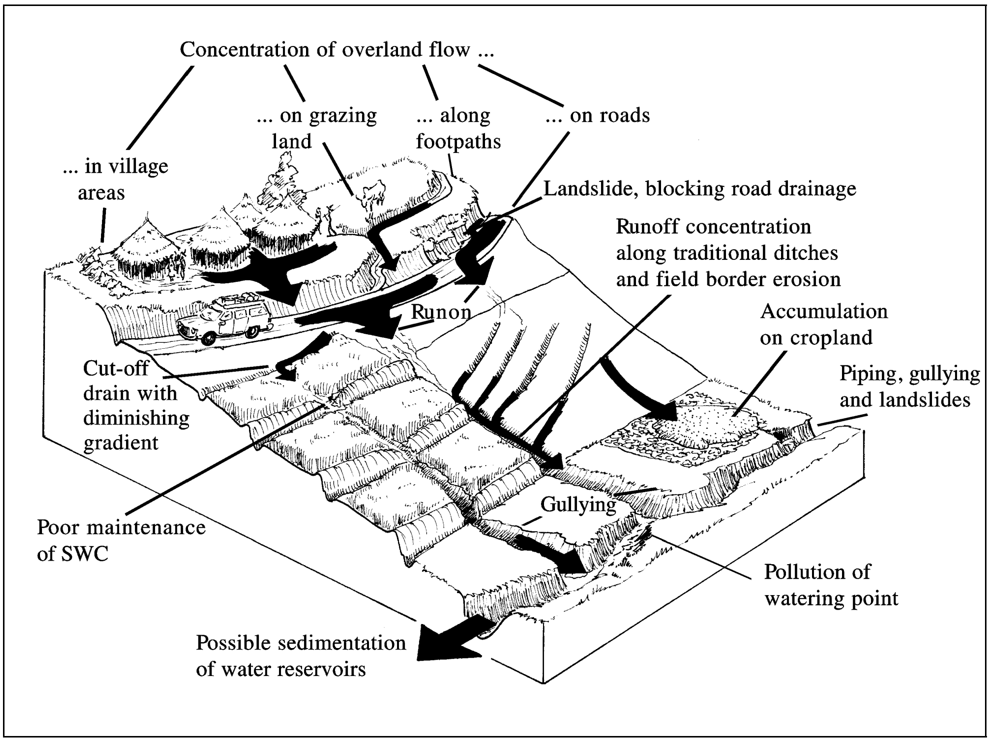


Figure 6: Erosion topo-sequence indicating the critical locations of soil erosion (Herweg & Stillhardt 1999)

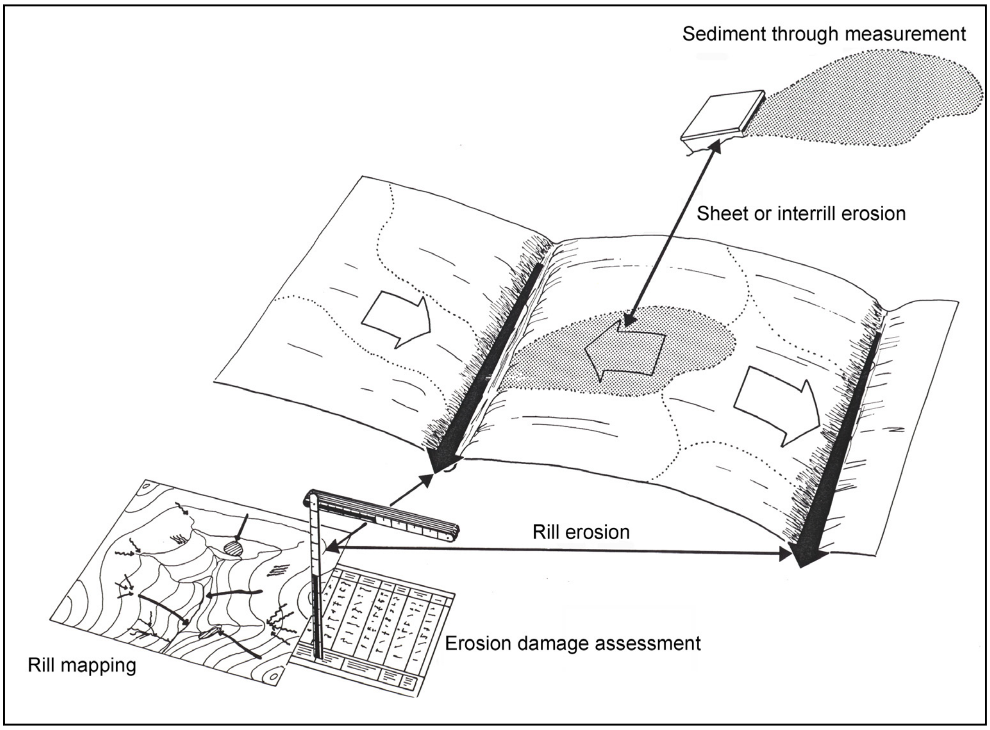


Figure 7: Combined use of sediment troughs and rill mapping (sketch: Herweg)

ACED measured rill erosion, gully erosion, and accumulations. Mapping was undertaken after severe rainstorms to estimate high soil loss at critical locations in a field or catchment (Figure 6). The date of the respective rainfall event provided the link of ACED with other measurements, such as rainfall amount and erosivity, soil loss and runoff (plots), and sediment yield and river discharge (hydrometric station). Thus, ACED indicated what happened during extreme events, but it was not used to obtain annual data. The volume of the erosion features was measured (m^3) and converted into tons by multiplying it by the bulk density of the soil. Sediment troughs and ACED can be used in combination (Figure 7).

Soil Conservation and Water Management

The impact of selected soil conservation measures on soil loss, runoff, crop yield and biomass production was tested on experimental plots (EP) of 180 m^2 (6 x 30 m) each. In Afdeyu, the performances of level bund, level *Fanya Juu*, and level double ditch were monitored against a control plot representing the prevailing farming practice. These measures represent those of the introduced SWC structures that are most widely used in the Ethiopian highlands. Data collection took place as described in the section above (Herweg & Ludi 1999).

Social and Economic Characteristics

The term "socio-economic" includes social, economic, cultural and demographic aspects. Under the SCRP standard programme, basic socio-economic information was gathered at irregular intervals using random sampling techniques. More detailed information was collected under the supplementary programme but only in a few SCRP stations (e.g. Galizia 1986, Tsehai Berhane-Selassie 1994, Ludi 1997, Dawod et al., 1999). Kappel (1996) presented a general methodology for the economic analysis of soil conservation. In response to the growing awareness that farmers' socio-economic situation, their livelihood strategies and indigenous knowledge are as important for the adaptation and effectiveness of SWC measures as biophysical data, Wiesmann et al. (1996) designed a new socio-economic research approach for the SCRP.

Following the severe droughts of 1972/73 and 1984/85, SWC measures were broadly introduced through mass Food-for-Work campaigns. Discussions soon followed as to how far the measures were truly accepted by farmers. The concept of 'acceptance' has never been clearly defined. The main reason for this may be that 'acceptance' - or its opposite, 'rejection' - does not reflect reality. Farmers often took part in a process where new SWC measures were tested, in many cases they eventually merged the measures with their own traditional SWC techniques. But farmers did not simply accept or reject the measures, they rather 'modified' or 'adapted' them. Consequently, there was a need to move away from the too simplistic concept of adoption versus non-adoption, and to modify the research approach accordingly:

At the conceptual level, it was observed that:

- farmers' use, maintenance and development of SWC must form the core of any new research activity.
- The adaptation of SWC measures, their modification and the reasons why they are modified must constitute the main focus of research.
- Besides the meso-level (catchment), more importance should be given to investigating at the 'micro-level' (household and plot).
- Potentials and limitations of SWC must be examined at different levels: community (addressing the question of awareness), household (addressing the question of means), plot (addressing the question of technologies).
- Independent / indigenous variables must be separated from dependent / external variables to clarify to what extent SWC is the result of the communities' own histories, or of a government input instead.

At the methodological level, it was observed that:

It is necessary to concentrate on household and community / PA level in socio-economic investigations, as 'catchments' or 'research units' do not represent social units of decision-making. Farmers with additional plots outside the catchment, as well as farmers living only from plots outside the catchment, have to be included in observations for the study to be statistically sound and representative. The analysis of problems and strategies at the community, household and plot levels leads to the determination of starting points for the promotion of more successful SWC.

The concept for further work in this direction was designed by Wiesmann and Ott (1996, Table 4).

Table 4: Overall concept of socio-economic research: levels of investigation

Main levels:	**Community, household, plot**

Starting point for socio-economic research:

- Socio-economic research within the SCRP addresses the main levels of the community, household and plot, and combines them methodologically.
- The resulting relationship is further assessed through household investigations.

Investigation level 1:	**Community or Peasant Association (PA)**

aims:

- to show the different exposure of communities to external input with regard to SWC;
- to identify historical / socio-cultural aspects and differences that influence farmers' attitudes to SWC;

methodology:

- assessment of PAs' SWC history with special reference to external SWC influence / input, and the communities' response: to be carried out through qualitative interviews and literature analysis;

result:

- historical, qualitative description (community profile);

Investigation level 2:	**All Households within a peasant association (PA)**

aims:

- to obtain an overview of the population and household structure in the PA;
- to carry out a preliminary investigation of farming systems with respect to the relations between livestock and crop production;
- to define a basis for household sample investigations from the existing socio-economic stratification;

methodology:

- collection of information from additional sources, mainly from PA databases;
- preparation of a wealth ranking by local informants / resource persons based on the PA data;
- where possible, location of plots (inside / outside catchment) will always be recorded;

result:

- quantitative database for sound, comparable HH sampling in all study areas (population profile, farming system profile);

Investigation level 3:	**Randomly sampled households**

Remarks:

A stratified random sampling among all households in a PA and their plots provides a statistically representative database. The location of a plot inside or outside the catchment is one variable. The study addresses the households and plot levels in detail.

aims:

- to obtain the arguments households make for their treatment of plots
- to evaluate whether and why households treat their plots differently
- to identify household characteristics which correlate with certain SWC approaches
- to evaluate factors that have a supporting or limiting effect on the response of households to SWC (level of farming system and household strategies)
- to identify possible SWC approaches to the households

methodology:

- semi-structured interviews with quantitative and qualitative aspects carried out by well-trained personnel

result:

- quantitative/qualitative data on households and SWC (household profile)

Table 4, continued

Investigation level 4:	**Plots of sampled households**
aims: – to obtain an inventory of SWC techniques used – to relate SWC practices (and the reasons for their application) to variations of the biophysical characteristics of the plots – to relate SWC practices to the HH structure and strategies, arising from Investigation Level 3 (socio-economic / socio-cultural component) **methodology:** – identification of plots owned by different HHs – monitoring of farming activities on these plots – assessment of conditions and changes on these plots **results:** – assessment of the use, maintenance and modification of SWC – dependency of SWC on a) biophysical characteristics and b) household structures (arising from Investigation Level 2) (technology profile)	

Investigation level 5:	**Case studies on specific topics**
aim: – to follow-up important questions that arise during investigations **methodology:** – varies with topics arising; – sampling bases on level 2 (overall database) **result:** – in-depth information on existing gaps in knowledge about people's survival strategies	

Management and Interpretation of Data

As explained in the previous chapters, the SCRP collected data and information of different kinds, resolution, and accuracy. In order to respond to requests from decision-makers, planners, extension agents, etc., the data need to be *linked* in various ways. In a few cases, such links can be of a quantitative nature. For example, rainfall, runoff and discharge can easily be combined since they are all documented in the same unit (mm). Other data, such as soil loss and sediment yield, need to be transformed (from t/ha into mm of topsoil loss), in order to be linked with ACED data (rill mapping). More often, however, the different types of data cannot be combined quantitatively, but only semi-quantitatively or qualitatively through a combination of measurement, interpretation and judgement. For example, EP data can help identify suitable SWC measures. But the information gained from socio-economic surveys, such as the factors that prevent farmers from applying SWC, is more important.

The programme developed a basic data management concept, from data collection in the field to analysis and final interpretation. The left side of the figure shows the general data management concept, while the right side indicates the example of the corresponding erosion data management.

Primary or raw data are divided into two parts. The dynamic part contains all measurements of variables made during each erosion event, while the constant part describes parameters which are not supposed to change, at least not within one cropping season or year. Some of the parameters require a particular estimation procedure, such as slot divisor calibration or derivation of the sediment concentration in suspension. All field data, including average calculations of water depth, estimated parameters, and laboratory data are entered into the main transformer, in this case the plot soil loss/runoff calculation formula. The results of the calculation – output data of the test plot measurements - are considered *secondary data* (t/ha of soil loss, mm of runoff). They can be used as input data for a model (algorithm) of a higher order, passing through a series of tests (extremes, plausibility, error, etc.) before they appear as monthly or annual time series for each plot.

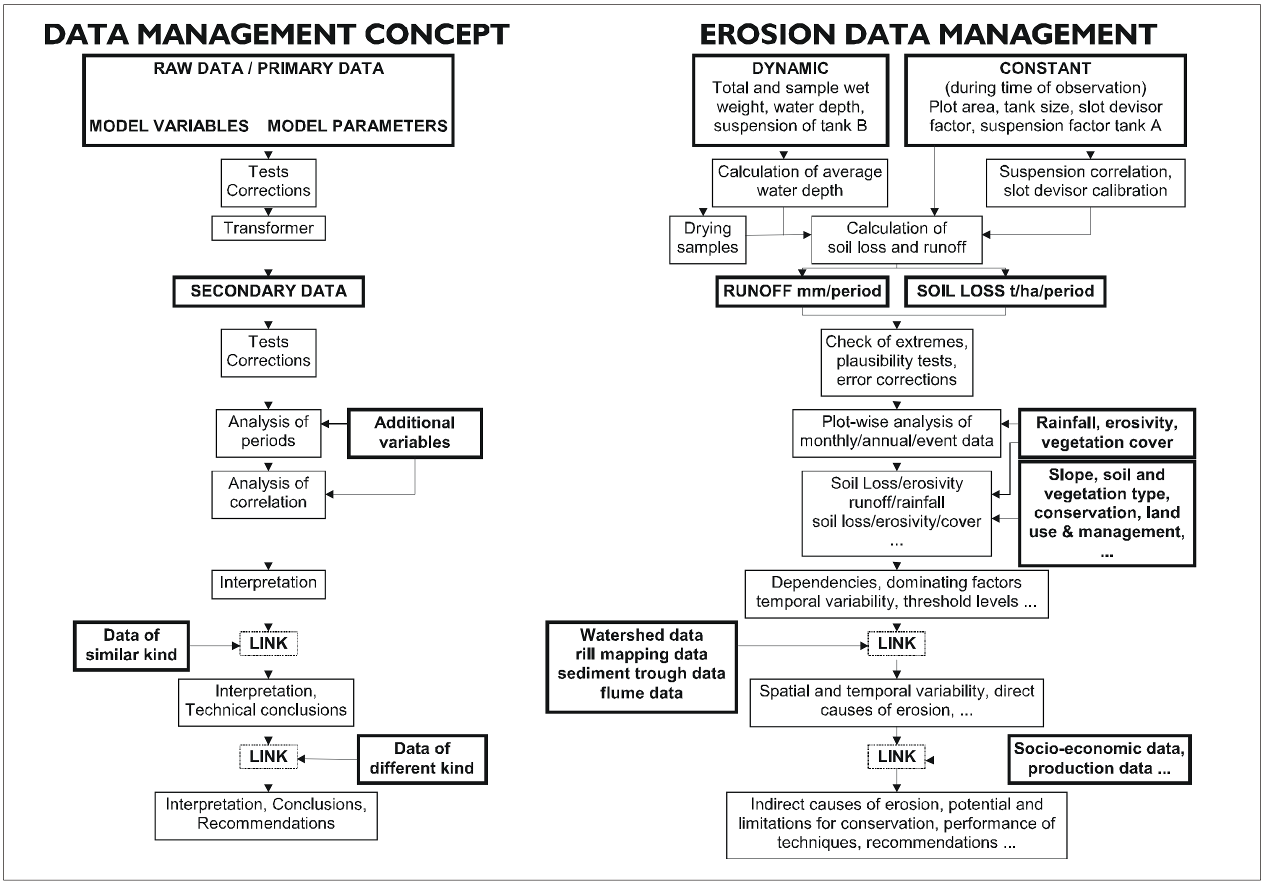


Figure 8: Data management concept (Herweg & Ostrowski 1997)

Soil loss and runoff are later linked (e.g. correlated) with *additional variables*, such as rainfall, erosivity, and vegetation cover, allowing initial interpretation of the temporal variability of soil erosion. Then, other parameters such as slope gradient, soil type, type and cover of vegetation, land use and land management, soil conservation practices, etc., can be considered in another correlation analysis, leading to an interpretation of interrelations, dependencies, causes, and effects of factors related to soil erosion. At the next stage, plot results can be linked with *data of a similar kind* from other levels of erosion measurement, such as gauging stations, sediment troughs, and ACED. In this way, spatial and temporal variability, average and extreme patterns, as well as several direct causes of erosion can be assessed. It is then possible to draw certain "technical" conclusions, e.g. regarding the timing of SWC activities and critical locations that require special attention, what plant cover is necessary for effective soil protection, hazardous land use and land management, etc. Eventually though, erosion data must be linked in a qualitative or semi-quantitative manner with *data of a different kind* which describe the socio-economic, political, and cultural framework under which farmers implement SWC. Technical information about the impact of SWC measures on soil erosion is meaningless when it comes to implementation, unless it is supplemented, for example, by an analysis of the economic viability and cultural adaptability of SWC measures.

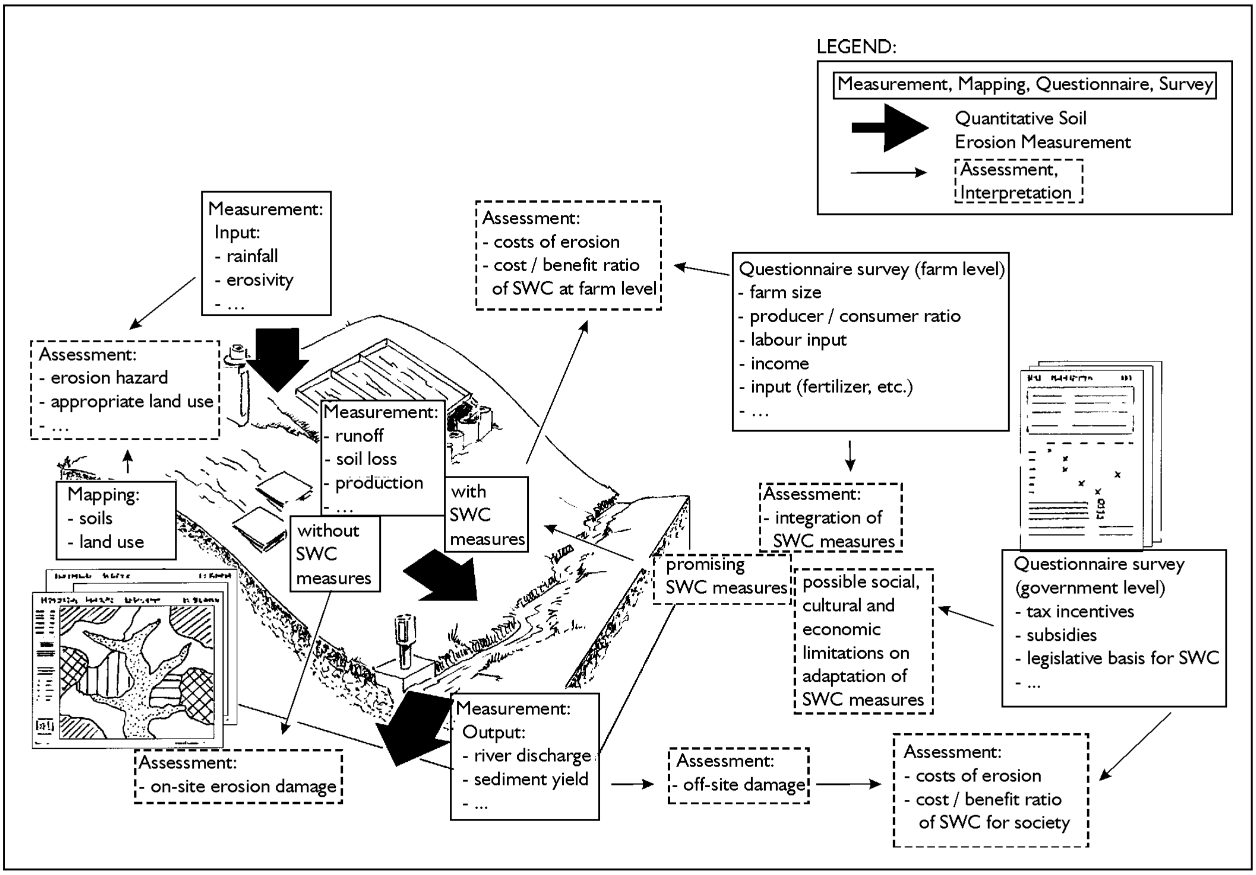


Figure 9: A structural model showing how measurements, surveys, assessments and interpretation can be linked (sketch: Herweg).

Figure 9 shows a structural model that helps to link measurements and observations with assessments and interpretations of practical relevance. For example:

- the results of soil, topographic and land use mapping (cf. Figure 8: additional variables),
- erosion measurements and observations represented by plots, hydrometric station, sediment troughs and ACED (cf. Figure 8: data of similar kind),
- and socio-economic surveys (cf. Figure 8: data of different kind).

Some of the assessments and interpretations are useful to design protective and productive SWC measures together with farmers, others assist planners and decision-makers in developing supportive activities at the regional or national levels, to identify priority areas for SWC.

Part II

Database and Data Overview

Soils

Geology

The Afdeyu area is part of the Precambrian Basement. The formation is about 810 million years old (Proterozoic). The rocky outcrops consist of highly metamorphic schist of originally volcanic material with intermediate to felsic chemical properties. The schists are partly laterizated. There is a steep angle of dip in most parts of the catchment. Numerous quartz-veins pass through the rocks. (Dawod et al, 1999).

Soil Classification

According to the National Map of Eritrea, the dominant soil type is stony Cambisol. On ridges the Cambisols are associated with Lithosols and on valley floors with Fluvisols (Bosshart, 1997). In the traditional nomenclature the soils are classified in three classes (Awet Berhe, Bereket Mebrahtu, 1999):

- *Shiebet* is the most fertile soil of the area with the highest water retention capacity. This soil is relatively deep and has a high content of clay.
- *Keih-hamed* means “red soil”. It is a medium-textured soil with low soil fertility and a lower water retention capacity than the Shiebet.
- *Ba’akel* refers to soils with a high component of sand, low water retention capacity, and low soil fertility.

Physical Soil Properties

The generally shallow soils (see Table 5) of the area are fine-grained, texturally ranging from loam to silt clay loam (see Figure 11), and well drained. The most shallow soils have a depth of only 10 cm. Soil development through weathering and soil erosion has led to the actual soil pattern given in Figure 10, and Table 6 and 7.

Table 5: Soil depth of the soils from different spots in the Mayketin river catchment, Afdeyu (soil depth > 100 cm is taken as 100 cm to calculate the mean)

Site	Mean soil depth	Number of samples	Range of soil depth
Grat Hamushte river, upland areas	64 cm	22	20 - >100 cm
Grat Hamushte river, lower slopes	66 cm	6	17 - >100 cm
Aguari'e upland	58 cm	4	27 - >100 cm
Aguari'e plain	76 cm	6	52 - >100 cm
Irrigated upland (planned)	75 cm	5	30 - >100 cm
Irrigated plain (planned)	> 100 cm	5	all > 100 cm

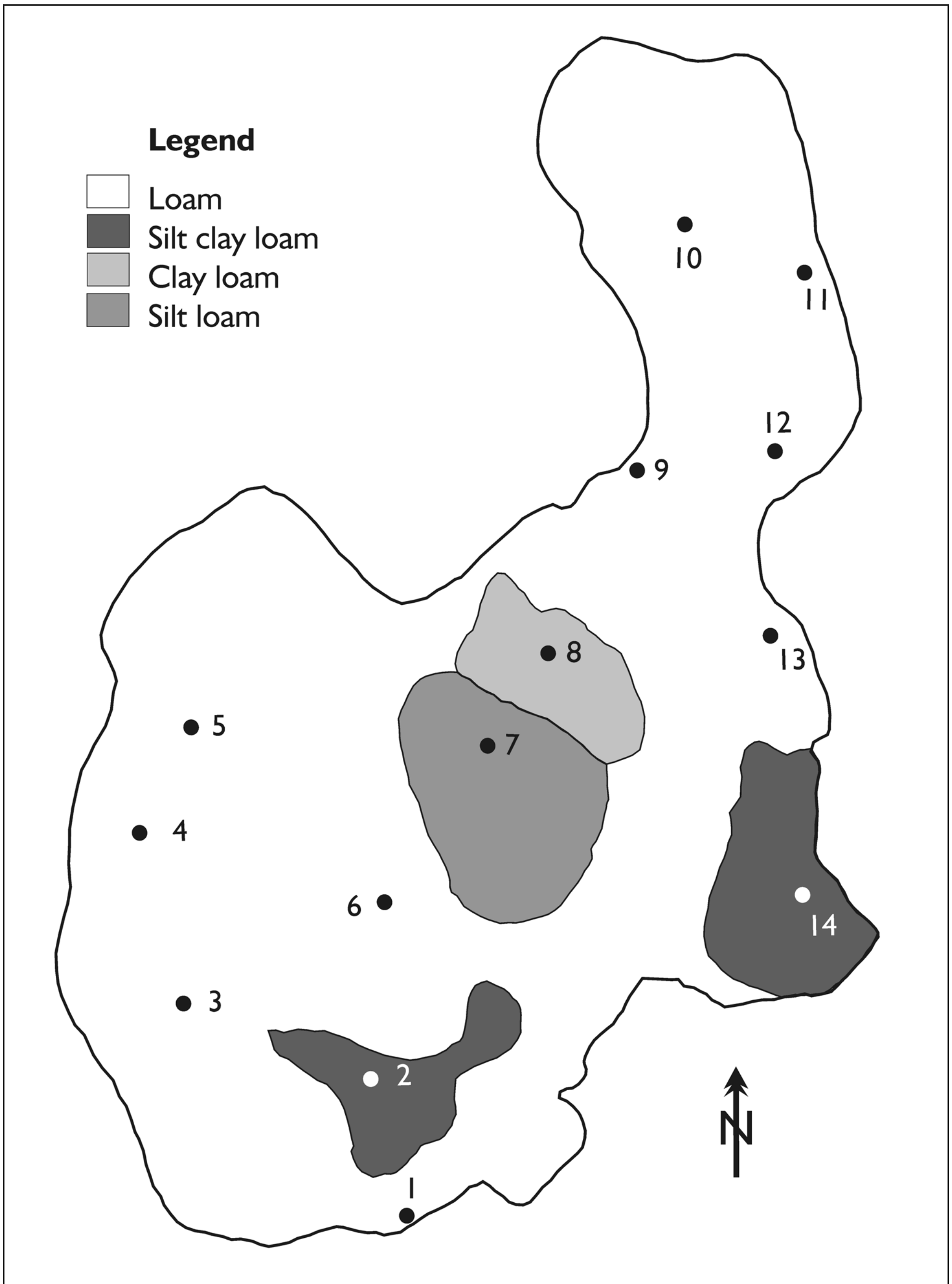
Source: Virginia Dawod, Semere Zaid, Lula Tekle, 1999

With regard to soil resistance against erosion, the soil texture (of fine earth, diameter 2 mm or less) is favourable, but the low content in organic matter leads to weak soil structure and, subsequently, to a high erosion risk. In certain parts of the catchment, the content of gravel and stones is remarkably high. The volume of gravel in the top layer is partially more than 50 %. While this percentage of gravel content reduces the area suitable for crop growing, it also protects topsoil from erosion and increases soil moisture by reducing evaporation.

Table 6: Soil texture of the soils from different plots

Plot	Sand %	Silt %	Clay %	Soil type	Soil colour
EP 1	55.6	30.5	13.9	Sandy loam	7.5 YR, light brown
EP 2	46.5	38.5	15	Loam	10 YR, brownish yellow
EP 3	40.8	41.5	17.7	Loam	10 YR, yellowish brown
EP 4	45.7	38.7	15.6	Loam	10 YR, yellowish brown
EP 5	39.2	42.1	18.7	Loam	10 YR, yellowish brown
TP 1	46.7	40.5	12.8	Loam	10 YR, brownish yellow
TP 2	30.5	49.7	19.8	Loam	10 YR, yellowish brown
TP 3	57.3	31.1	11.6	Sandy loam	7.5 YR, strong brown
TP 4	47.7	38.4	13.9	Loam	10 YR, light yellowish brown

Source: Michael Kidane Mebrahtu, 1997



1	Loam / Clay loam / Clay loam	2	Silt clay loam / Clay loam / Clay loam
3	Loam / Loam / Loam	4	Loam / Loam /Silt loam
5	Loam / Silt loam / Silt loam	6	Loam / Loam / Loam
7	Silt loam / Silt loam /Silt loam	8	Clay loam / Silt loam / Silt loam
9	Loam / Loam / Loam	10	Loam / Loam / Loam
11	Loam / Loam / Loam	12	Loam / Sandy loam / Sandy loam
13	Loam / Silt loam / Silt loam	14	Silt clay loam / Silt loam / Silt loam

Figure 10: Soil texture map of Mayketin river catchment, Afdeyu. 85 % of the catchment area is covered with loamy soils. Source: Michael Kidane Mebrahtu, 1997

Table 7: Soil texture of sample points in Figure 10

Site No	Soil depth	Sand %	Silt %	Clay %	Soil texture
1	0 - 6 cm	27.9	45.5	26.6	Loam
	30 - 36 cm	20.0	45.5	34.5	Clay loam
	60 - 66 cm	20.6	48.6	30.8	Clay loam
2	0 - 6 cm	14.8	49.1	36.1	Silt clay loam
	30 - 36 cm	25.3	45.8	28.9	Clay loam
	60 - 66 cm	24.6	47.5	27.9	Clay loam
3	0 - 6 cm	46.9	41.8	11.3	Loam
	30 - 36 cm	45.1	42.4	12.5	Loam
	60 - 66 cm	44.5	43.3	12.2	Loam
4	0 - 6 cm	43.5	43.2	13.3	Loam
	30 - 36 cm	48.2	42.6	9.2	Loam
	60 - 66 cm	30.0	51.4	18.6	Silt loam
5	0 - 6 cm	38.2	47.1	14.7	Loam
	30 - 36 cm	25.5	60.8	13.7	Silt loam
	60 - 66 cm	34.7	52.6	12.7	Silt loam
6	0 - 6 cm	47.9	41.1	11.0	Loam
	30 - 36 cm	40.9	42.7	16.4	Loam
	60 - 66 cm	42.4	40.3	17.3	Loam
7	0 - 6 cm	23.7	53.5	22.8	Silt loam
	30 - 36 cm	20.6	56.8	22.6	Silt loam
	60 - 66 cm	22.9	52.1	25.0	Silt loam
8	0 - 6 cm	21.8	47.7	30.5	Clay loam
	30 - 36 cm	25.5	52.6	21.9	Silt loam
	60 - 66 cm	13.8	57.7	28.7	Silt clay loam
9	0 - 6 cm	42.4	38.1	19.5	Loam
	30 - 36 cm	30.1	45.1	24.8	Loam
	60 - 66 cm	33.3	42.5	24.2	Loam
10	0 - 6 cm	42.6	41.4	14.0	Loam
	30 - 36 cm	39.9	37.3	22.8	Loam
	60 - 66 cm	47.6	33.6	18.8	Loam
11	0 - 6 cm	36.3	44.3	19.4	Loam
	30 - 36 cm	31.5	44.4	24.1	Loam
	60 - 66 cm	36.4	42.1	21.5	Loam
12	0 - 6 cm	58.9	29.8	11.3	Loam
	30 - 36 cm	51.7	36.9	11.4	Sandy loam
	60 - 66 cm	66.3	28.4	5.3	Sandy loam
13	0 - 6 cm	48.7	42.0	9.3	Loam
	30 - 36 cm	35.5	52.3	12.2	Silt loam
	60 - 66 cm	37.2	53.5	9.3	Silt loam
14	0 - 6 cm	22.9	46.6	30.5	Silt clay loam
	30 - 36 cm	30.8	49.3	19.9	Silt loam
	60 - 66 cm	28.9	53.8	17.3	Silt loam

Source: Ministry of Agriculture, Iyassu Ghebretatios, MoA, DARHRD 1997

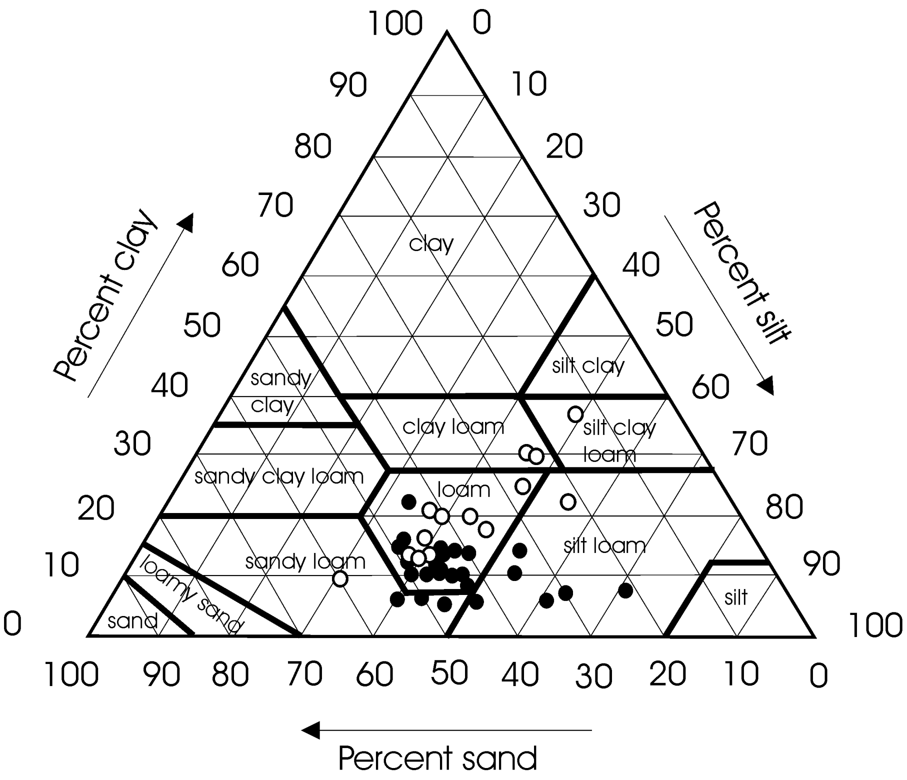


Figure 11: Range of topsoil texture in different locations of the Mayketin river catchment, Afdeyu. Source: Kidane Mebrahtu, 1997(white dots) and Ministry of Agriculture, Iyassu Ghebretatios, MoA, DARHRD 1997 (black dots)

Chemical Soil Properties

Interpretation of the results must be done with care because different analytical methods were used and the amount of analysis does not allow conclusive statements. Therefore, the suggestion is to take the results as indicative and perform in-depth analysis where more detailed information is needed. The information from different authors can be summarised as follows:

pH: The pH-value of most of the analysed samples is within the range preferred by most agricultural crops (pH 4.5 to 7.0). About 20 % of the measured pH (total sample size: 35) are above 7.10. Values higher than 7.0 can lead to a decreased availability of P and B and for some sensitive crops to decreased yield, but only one of the analysed samples is within the range where remarkable restrictions can be expected (pH 8.2). Of the crops panted in Afdeyu, the most sensitive to high pH values are wheat, potatoes and tomatoes.

Table 8: Chemical properties of the soils from different plots

			Soluble salts							Exchangeable cations						
	Ph	ECe	CO3 (g/l)	HCO3 (g/l)	Cl (g/l)	So4 (g/l)	Ca & Mg (g/l)	K (g/l)	Na (g/l)	TDS (ppm)	CaCO3 (%)	OM (%)	Na (meq/100 g)	K (meq/100 g)	Ca & Mg (meq/100 g)	P (ppm)
EP 1	7.21	0.08	0	0.02	0.02	v.l.	.024	.005	0	157	3.5	0.57	0.03	0.02	7.13	2.0
EP 2	7.25	0.11	0	0.03	0.02	v.l.	.032	.005	0	183	4.0	0.72	0.03	0.04	7.00	3.6
EP 3	7.05	0.09	0	0.03	0.02		.024	0	0	144	3.5	1.83	0.03	0.02	8.38	2.8
EP 4	7.08	0.12	0	0.03	0.02		.024	0	0	198	3.0	1.75	0.03	0.06	9.64	2.9
EP 5	7.03	0.08	0	0.03	0		.024	0	0	174	3.0	1.46	0.03	0.02	7.13	2.5
TP 1	6.96	0.05	0	0.02	0.02		.016	0	0	121	3.5	1.75	0.03	0.02	7.25	1.7
TP 2	7.08	0.14	0	0.03	0.02	low	.032	.001	0	203	3.5	3.95	0.46	0.10	17.0	14.6
TP 3	7.03	0.05	0	0.02	0.02	low	.016	0	0	106	3.5	0.82	0.03	0.02	4.75	1.7
TP 4	6.97	0.11	0	0.02	0.02	v.l.	.032	0	0	164	4.0	2.81	0.03	0.04	8.25	1.7

Source: Michael Kidane Mebrahtu, 1997 / v.l. = very low

EC_e: Assuming that measurement was taken from an undiluted soil solution extracted from wet soils, all measured values are very low. If irrigation water is also low in dissolved salts, hazard of salinity or sodicity is low.

TDS: (only on plots). Values are all low, interpretation is the same as for EC_e.

Exchangeable cations:

K (assuming that the ammonium acetate extraction was used): According to the rating for Central African soils all values on the plots are very low, application of K fertiliser is recommended for values < 0.2 me/100g. Exchangeable K levels are only of limited value for the prediction of crop response since they give no direct indication of the capacity of the soil to release currently unavailable K over a period of time.

Na: Although Na may, in particular circumstances, be utilised by some plants as a partial substitute for K, it is not an essential plant nutrient.

Mg and Ca: Concerning the degree to which these two elements are available to plants no detailed interpretation is possible, because only one total is presented. But the range of the results indicates that no problems occur.

$CaCO_3$: With 3-4 % of free carbonates in all analysed soil samples, no difficulties are to be expected.

Organic matter: Almost all measured values are low to very low. Higher contents of organic matter were measured only on two test plots: TP 2 with 3.95 % and TP 4 with 2.81 %.

P: The method of analysis is not known for the given samples. Therefore, a short, generalised table with the ranges of different methods is presented below.

Table 9: Indicative available P values of different methods [ppm]

Method	high	medium	low
Olsen 3 (0.5 M $NaHCO_3$)	> 15	15 - 5	< 5
Bray 4 (dilute HCl/NH_4F)	> 50	50 - 15	< 15
Nelson (dilute HCl/H_2SO_4)	> 30	30 - 10	< 10
Truog (dilute H_2SO_4)	> 40	40 - 20	< 20
Bingham (H_2O solution)	> 2	2 - 1	< 1
Morgan (Na acetate / acetic acid)	> 15	15 - 5	< 5
ADAS NH_4 acetate / acetic acid)	> 40	40 -	< 2

Without knowledge of the methods used to analyse the soil samples, it is difficult to interpret the results. Most measured parameters indicate that soil fertility is rather low. High land use dynamics, intensification of land use and the restricted application of fertiliser are most probably the reasons for this. The flood plain in the lower part of the catchment benefits from accumulation processes and is not affected by the low soil fertility. If shallow soils in the steeper parts of the catchment are combined with low soil fertility, problems of decreasing crop yield can occur.

Further reading

Research Reports:
Bosshart Urs, 1997

Other publications:
Landon, J.R., (editor) 1991 / Virginia Dawod, Semere Zaid, Lula Tekle, 1999

Theses:
Awet Berhe, Bereket Mebrahtu 1999 / Michael Kidane Mebrahtu, 1997 / Semere Zaid Ghebremedhin, 1998

Maps:
Governement of the State of Eritrea, 1995

Climate

Table 10 shows the climatic data collected in relation to soil erosion and conservation process monitoring.

Table 10: Climate in Afdeyu: type of data collected, duration of collection, and measurement technique

Parameter	Device / method	Availability in database*	Data source file (primary database)**	Resolution and frequency of data collection
Amount and intensity of rainfall	Pluviometer/ Pluviograph (monthly chartrolls)	01.07.1984 - 31.12.1998	afyyplre.dbf***	Segments of similar rainfall intensities
Erosivity	Calculation on the basis of rainfall energy and duration	01.07.1984 - 31.12.1998	afyy_a03.dbf (secondary database)	Per storm
Rainfall direction and inclination	Inclinometer****	01.01.1986 - 31.12.1998	afyyinri.dbf	Daily
Air temperature (min. and max.)	Thermometer, 1.5 m above ground	01.01.1986 - 31.12.1998	afyycscd.dbf	At 8 a.m. and 6 p.m.
Soil surface temperature (min. and max.)	Thermometer, 0.1 m above soil surface	01.01.1986 - 31.12.1998	afyycscd.dbf	At 8 a.m. and 6 p.m.
Evaporation	Piche tube evaporimeter	01.01.1986 - 31.12.1998	afyycscd.dbf	At 8 a.m. and 6 p.m.
Wind direction and strength	Observation	01.01.1986 - 31.12.1998	afyycscd.dbf	At 8 a.m. and 6 p.m.

Notes: *Due to political and institutional problems, the data from 1991 to 1993 are not available in a digital format.

**In the file names, the letters "af" stand for the station name (Afdeyu), "yy" for year, and the other four letters identify the content of the respective file (e.g. filename af87cscd.dbf = Afdeyu / 1987 / climatic station climatic data).

***This file contains the amount for each interval of constant intensity within the same rainfall event. For further analysis these amounts are summarised as storm values. Definition of a storm: the minimum amount of rainfall must be 12.5 mm; one event must be separated from the next or previous one by at least 6 hours.

****Developed by H. Hurni in 1981 (published in 1996).

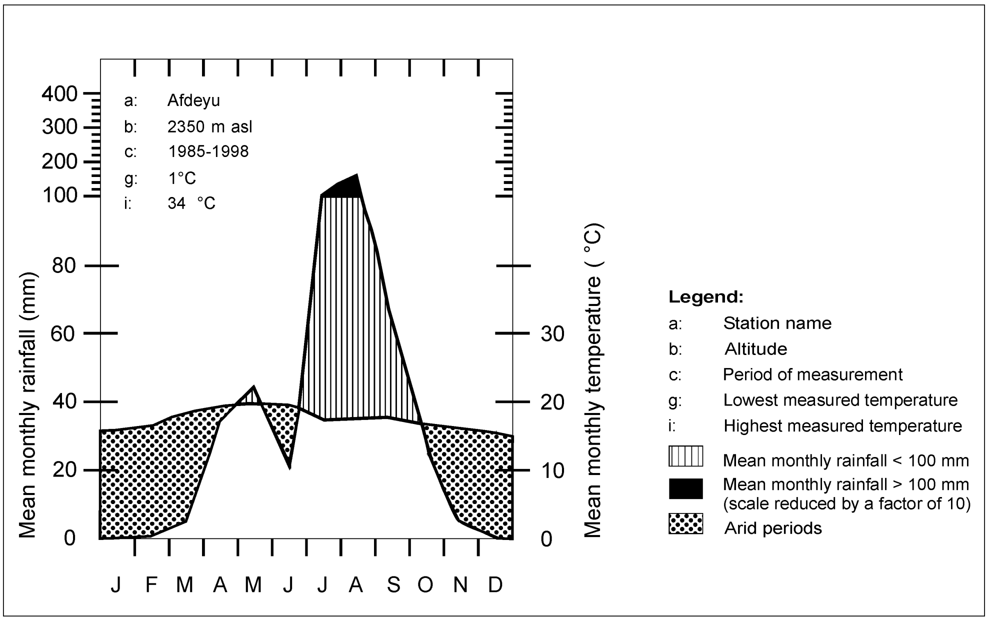


Figure 12: Climatic diagram for Afdeyu

Afdeyu is located in the *Kebesa* zone (> 2000 m asl, SCRP: *Weyna Dega*). Figure 12 shows the standardised climatic diagram of Afdeyu (according to Walter, 1964): In some years, there is a bimodal rainfall regime, but the variability during the small rainy season is great and rainfall is often erratic. During two months the amount of rainfall exceeds 100 mm. The months from November to April and the month of June show arid conditions. The index of aridity, for these seven months according to de Martonne and Lauer (1984), is below 20. In the Walter diagram, the rainfall curve drops below the temperature curve.

Rainfall

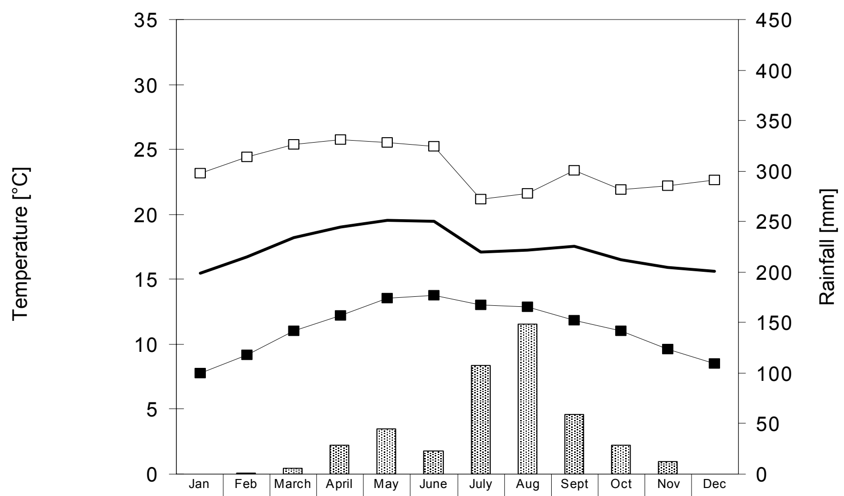
Amount of Rainfall

The general rainfall pattern is shown in Figure 13. Daily measurements of the period from 1985 to 1998 are grouped by month or year, and averaged. The measurements of 1984 are excluded from analysis (first, incomplete year).

The main results can be summarised as follows:

- Mean amount of days with rainfall events per year: 53
- Minimum amount of days with rainfall events per year: 24 (1990)
- Maximum amount of days with rainfall events per year: 69 (1985)
- Mean amount of days with erosive storm events per year: 6.5 (definition of erosive storms: the minimum amount of rainfall must be 12.5 mm; one event must be separated from the next or the previous one by at least 6 hours)
- Minimum amount of days with storm events per year: 2 (1985)
- Maximum amount of days with storm events per year: 14 (1998)

- Mean annual amount of rainfall: 458 mm
- Minimum annual amount of rainfall: 259 mm (1989)
- Maximum annual amount of rainfall: 658 mm (1995)
- Mean minimum amount of rainfall per month: 0 mm (Dec. and Jan.)
- Mean maximum amount of rainfall per month 148 mm (August)
- Maximum amount of rainfall during a single event: 96.0 mm (in 1998, 38 % of the monthly total of 250.4 mm)



	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Rainfall [mm]	0.0	0.7	5.4	28.2	44.9	22.6	107.7	148.4	59.4	28.5	12.0	0.0
Average monthly minimum air temperature	7.7	9.2	11.0	12.2	13.6	13.8	13.0	12.9	11.8	11.0	9.6	8.5
Average monthly maximum air temperature	23.2	24.4	25.4	25.8	25.6	25.2	21.2	21.6	23.4	21.9	22.2	22.7
Average monthly air temperature	15.5	16.7	18.2	19.1	19.5	19.5	17.1	17.2	17.6	16.5	15.9	15.6

Figure 13: Mean monthly rainfall and mean monthly air temperature (missing data of 1991 - 1994)

Intensity and Erosivity of Rainfall

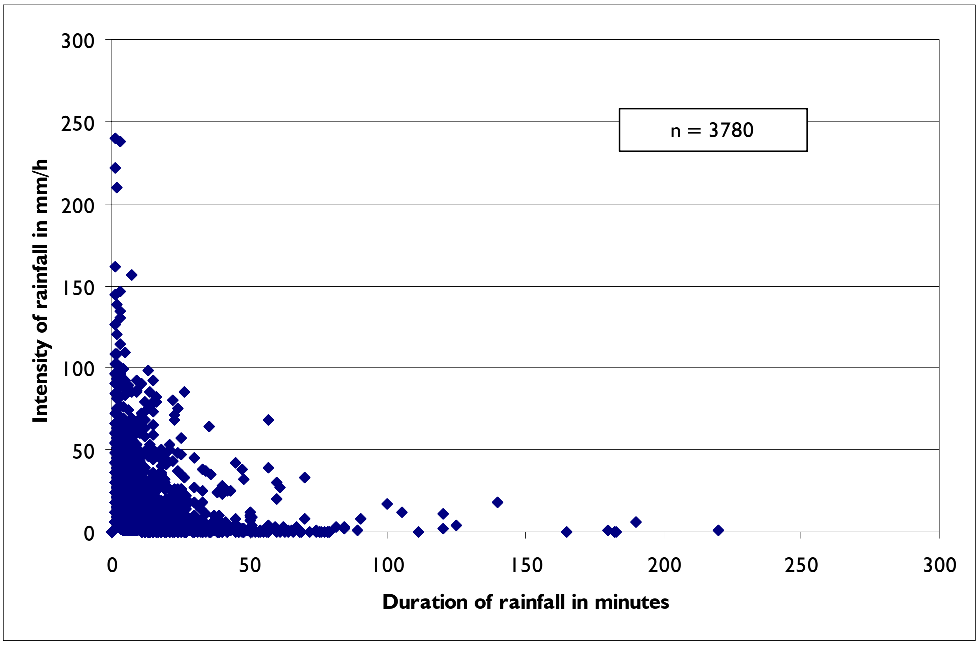
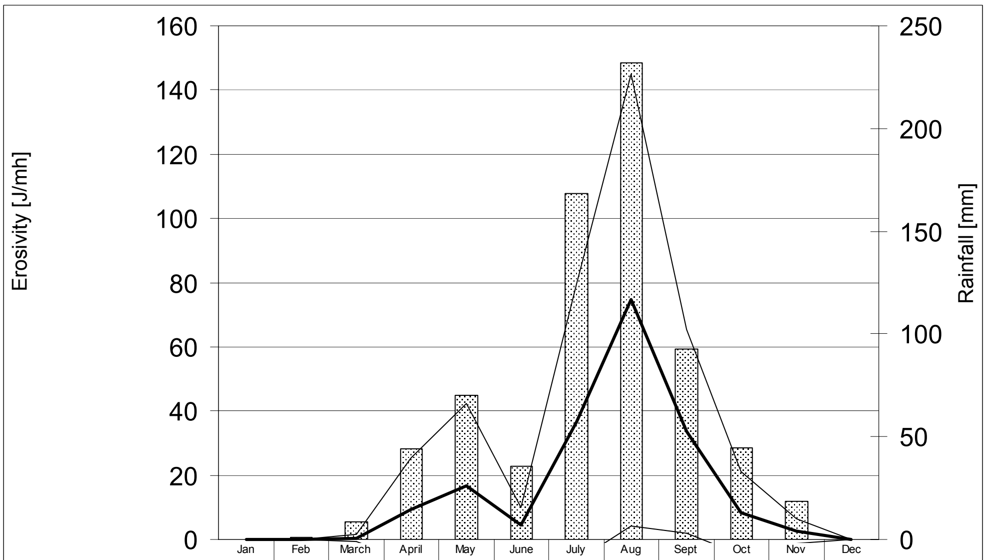


Figure 14: Relation between intensity and duration of rainfall (1984 - 1998, Afdeyu). Each dot represents an interval of similar intensity in any given event.



	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Rainfall [mm]	0.0	0.7	5.4	28.2	44.9	22.6	107.7	148.4	59.4	28.5	12.0	0.0
Mean monthly erosivity	0.0	0.0	0.7	14.5	25.9	6.9	57.0	116.5	52.5	12.8	4.0	0.0
Mean plus one standard deviation	0.0	0.0	2.5	39.7	66.4	15.6	124.4	226.5	102.1	33.0	10.1	0.0
Mean minus one standard deviation	0.0	0.0	-1.0	-10.8	-14.5	-1.8	-10.4	6.6	2.9	-7.4	-2.2	0.0

Figure 15: Mean monthly erosivity and mean monthly rainfall (1985 - 1998)

Duration and amount of rainfall contain information about the intensity of an event (mm/h). Figure 14 shows the relation between the two measurements. The maximum duration is limited to 300 minutes (5 hours). Rainfall had its greatest intensities during storms of short rainfall duration, while rainfall with low intensity was usually of long duration.

Rainfall erosivity (J/mh) is calculated on the basis of Wischmeier and Smith (1965). One intense single rainfall event can cause almost 100 % of the total monthly soil loss (40.8 of 41.5 t/ha), e.g. the event of 27 July 1988 with 89.1 mm of rainfall and an erosivity of 187.7 J/mh.

Figure 15 represents the mean monthly erosivity and the mean monthly rainfall with the confidence interval of one standard deviation. In Afdeyu, both erosivity and rainfall regime are bimodal, peaking in May and July / August.

Direction of Rainfall

Direction of rainfall is compiled for the period from 1986 to 1998: Figure 16 and Table 11 show the results of the measurements. The dominant wind direction is from the east (see Figure 19), the dominant direction of rainfalls is spread from northwest to southeast. In 89 % of all recorded events, rainfall started in the afternoon.

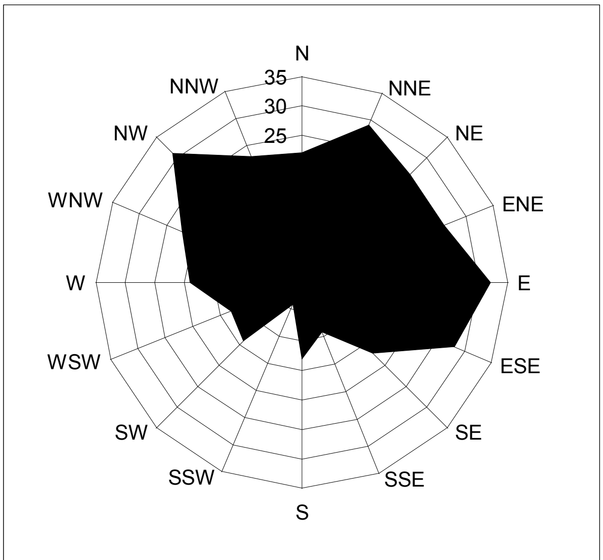


Figure 16: Direction of rainfall (1986 - 1998, Afdeyu). The frequency of the rainfall events submitted to analysis is indicated on the vertical axis.

Table 11: Monthly and annual frequency of rainfall events according to rainfall direction (1986 - 1998, Afdeyu)

Year	E	ENE	ESE	N	NE	NNE	NNW	NW	S	SE	SSE	SSW	SW	W	WN	WSW
1986	3	2	2	7	3	6	3	5	0	1	0	1	0	0	0	0
1987	3	2	1	6	1	2	4	2	0	2	2	0	2	1	1	1
1988	5	2	5	0	2	4	2	5	0	2	1	2	2	2	2	2
1989	3	5	4	1	1	3	1	1	0	2	1	1	2	3	2	0
1990	5	2	2	1	2	1	1	4	0	1	1	0	2	0	0	1
1991	3	5	3	2	6	1	2	0	2	0	1	0	2	3	7	1
1994	3	1	6	1	6	6	3	2	7	4	0	0	0	5	5	3
1995	0	1	2	3	5	5	6	8	2	2	2	0	1	3	2	3
1998	7	6	3	1	0	1	1	4	2	3	1	0	3	2	3	2

Temperature

Air Temperature

Air temperature was measured on a daily basis 1.5 m above ground for the period from 1986 to 1998. Figure 17 shows a one year time line of the averaged data: mean, minimum, and maximum daily air temperature (n = 3985). Main results of measurements are:

- range of daily minimum air temperature: 1 °C (measured four times) and 20 °C (measured once)
- range of daily maximum air temperature: 13 °C (measured once) and 34 °C (measured five times, all in March 1986)
- mean daily minimum air temperature: 11.2 °C
- mean daily maximum air temperature: 23.5 °Cmean daily air temperature: 17.4 °C

Table 12 lists the monthly and annual air temperatures. The mean monthly temperatures range from 15.5 °C in January to 19.5 °C in May.

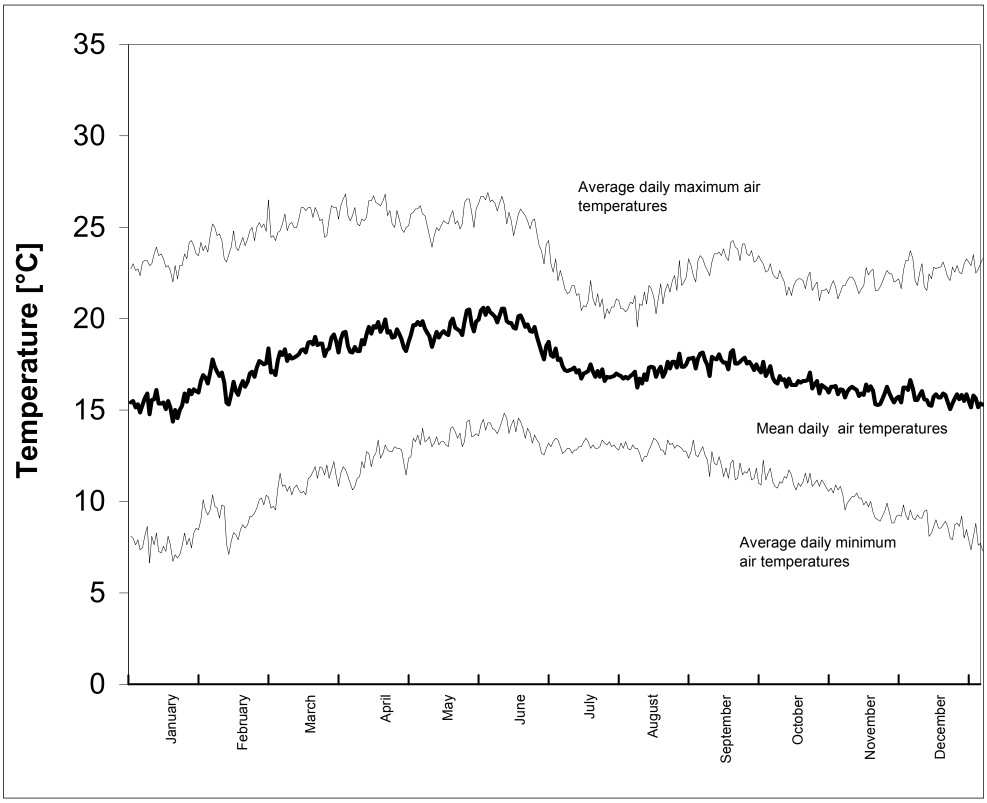


Figure 17: Mean daily air temperatures, and mean daily minimum and maximum air temperatures (1986 - 1998, Afdeyu. No data for 1992 and 1993)

Table 12: Mean monthly and annual air temperatures in °C (1986 - 1998, Afdeyu)

Month	Monthly minimum	Monthly maximum	Monthly mean
January	7.7	23.2	15.5
February	9.2	24.4	16.7
March	11.0	25.4	18.2
April	12.2	25.8	19.1
May	13.6	25.6	19.5
June	13.7	25.2	19.2
July	13.0	21.2	17.1
August	12.9	21.6	17.2
September	11.8	23.4	17.6
October	11.0	21.9	16.5
November	9.6	22.2	15.9
December	8.5	22.7	15.6

Year	Annual mean
1986	20.2
1987	18.8
1988	16.8
1989	16.5
1990	17.2
1991	17.0
1994	16.7
1995	16.9
1996	16.9
1997	17.0
1998	17.1

Soil Surface Temperature

In the period between 1988 and 1994, soil surface temperature was measured twice daily at 0.10 m above ground under shelter. Figure 18 shows the averaged data on a one-year time line (n = 3013).

In more than 98 % of the records, mean daily soil surface temperature was higher than mean daily air temperature. The temperature difference between air and soil surface was greater during the dry season than during the rainy season. With a few exceptions, the daily temperature range at soil surface was greater than that in the air.

Soil surface temperature is more sensitive to seasonal weather variations than air temperature. Heat insulation and radiation of the soil are most intense during the dry season after the rainfall season. At this time of the year, soil surface maximum temperatures were relatively high and soil surface minimum temperatures relatively low. In contrast to the air temperature, soil surface temperature reached values below zero. Frost during the night was measured only on two consecutive days in January 1989. Table 13 shows monthly and annual soil surface temperatures.

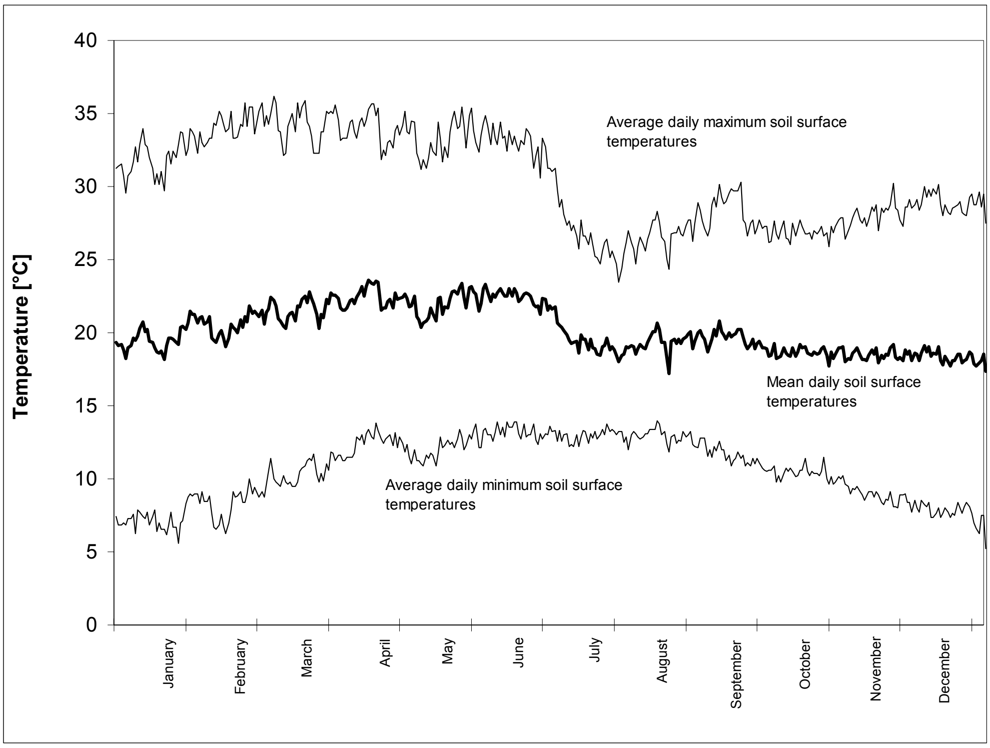


Figure 18: Mean daily soil surface temperatures, and mean daily minimum and maximum soil temperatures (1988 - 1998, Afdeyu)

Table 13: Monthly and annual soil surface temperatures (1989 - 1998, Afdeyu)

	Monthly minimum	Monthly maximum	Monthly mean
January	7.1	31.8	19.5
February	8.3	34.0	20.5
March	10.2	34.3	21.6
April	12.4	34.0	22.4
May	12.1	33.4	22.0
June	13.1	33.1	22.4
July	13.0	26.9	19.5
August	12.9	26.6	19.3
September	11.6	28.3	19.6
October	10.4	26.9	18.6
November	8.8	28.1	18.5
December	7.7	28.9	18.3

Year	Annual mean
1989	18.2
1990	20.2
1991	20.4
1994	22.7
1995	21.8
1996	21.0
1997	20.6
1998	19.0

Wind

Wind direction is analysed for the period from 1986 to 1998, observed twice a day (8 a.m. and 6 p.m.) by a thread fixed on a pole. Wind is roughly described by the four classes: no wind/ weak wind/ medium wind/ strong wind. As shown in Figure 19 and Tables 14 and 15, the most frequent wind direction in the morning was from the east, in the evening from the east and the west. No wind was observed in only 9 % of the observations in the morning and in only 1.5 % in the evening.

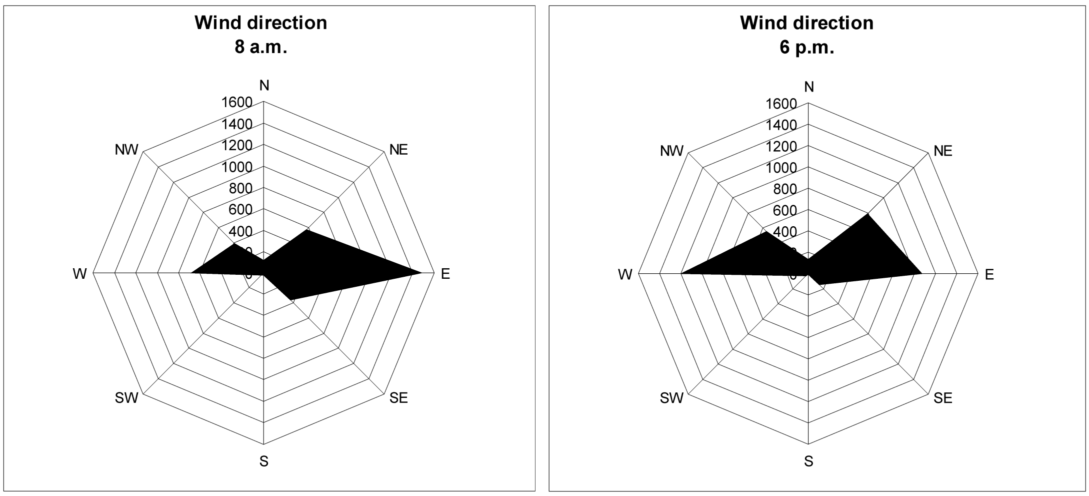


Figure 19: Wind direction and frequency at 8 a.m. (left) and at 6 p.m. (right) (1986 - 1998, Afdeyu). The frequency of directions is given on the vertical axis.

Table 14: Annual frequency of winds according to wind direction at 8 a.m. (1986 - 1998, Afdeyu)

Year	N	NW	W	SW	S	SE	E	NE	Total
1986	9	57	38	0	0	16	157	88	365
1987	1	44	64	0	0	7	208	38	362
1988	6	22	92	1	1	23	194	8	347
1989	2	16	116	10	2	23	159	18	346
1990	5	70	83	4	0	56	91	21	330
1991	1	39	62	0	3	72	105	22	304
1994	5	50	35	1	5	40	92	83	311
1995	13	33	39	7	1	20	93	84	290
1996	35	22	48	0	4	13	128	68	318
1997	27	9	39	3	1	50	129	65	323
1998	15	20	55	0	2	39	113	70	314

Table 15: Annual frequency of winds according to wind direction at 6 p.m. (1986 - 1998, Afdeyu)

Year	N	NW	W	SW	S	SE	E	NE	Total
1986	7	111	89	1	0	5	75	76	364
1987	1	78	130	0	1	3	121	30	364
1988	1	14	152	2	0	15	149	23	356
1989	6	27	167	3	0	16	114	26	359
1990	1	69	108	1	0	14	108	40	341
1991	0	58	102	0	3	13	124	43	343
1994	5	48	87	5	0	13	81	117	356
1995	21	50	90	8	0	10	64	117	360
1996	52	21	93	5	1	8	61	119	360
1997	21	31	93	5	1	18	84	103	356
1998	16	43	81	4	1	31	85	98	359

Evaporation

Evaporation in Afdeyu is measured by a Piche tube evaporimeter, data are compiled for the period between 1986 and 1998. Figure 20 shows the average daily evaporation values on a one-year time line with the confidence interval of one standard deviation. The data for 1992 and 1993 are missing because of political changes after the liberation. Highest mean monthly evaporation measured by Piche tube evaporimeter occurred during the dry season, especially in December/January. Evaporation drops with the beginning of the rainy season in May. Table 16 lists the mean daily evaporation for the period from 1986 to 1998.

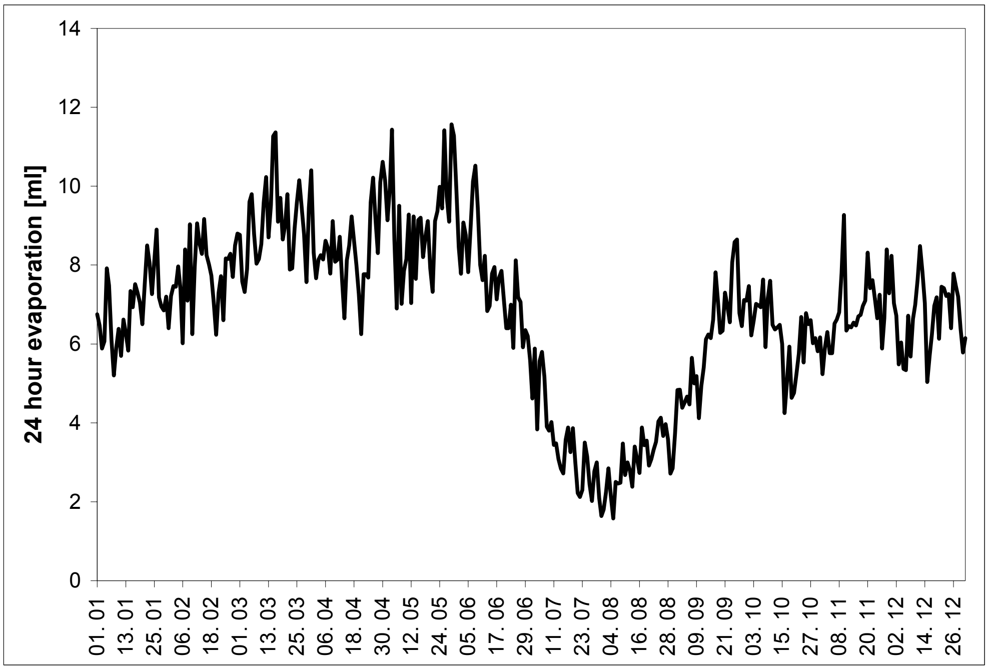


Figure 20: Evaporation measured by Piche tube evaporimeter (1986 - 1998, Afdeyu). The daily 24-hour period started at 8 a.m.

Table 16: Mean daily evaporation [ml] per month (1986 - 1998, Afdeyu). No data for 1992 and 1993

	1987	**1988**	**1998**	**1990**	**1991**	**1994**	**1995**	**1996**	**1997**	**1998**	**Mean**
January	6.7	7.7	6.4	5.8	6.8	8.3	7.4	6.7	6.6	5.5	6.8
February	7.3	9.2	7.4	7.0	7.5	7.5	8.4	7.7	8.1	7.2	7.7
March	8.2	11.2	8.2	7.7	8.4	9.0	8.6	7.4	8.5	7.9	8.5
April	8.8	9.3	7.5	9.1	7.3	8.6	7.1	7.0	7.7	9.2	8.2
May	5.8	9.9	9.5	11.3	8.8	8.9	7.6	6.5	5.6	7.6	8.1
June	6.9	8.6	8.6	8.9	5.6	5.7	8.4	4.2	5.5	6.9	6.9
July	6.3	2.8	4.3	3.9	3.0	1.7	1.9	3.0	1.6	2.1	3.0
August	2.9	2.1	2.6	4.9	2.1	1.6	1.6	1.5	2.6	1.0	2.3
September	7.7	5.3	6.3	6.6	6.4	4.0	4.7	5.5	7.2	3.7	5.7
October	5.2	6.6	5.6	7.7	6.9	5.9	6.3	7.2	3.9	5.8	6.1
November	8.3	6.3	7.3	7.6	6.2	5.5	5.3	4.9	3.3	5.5	6.0
December	7.4	6.3	6.0	7.7	6.0	5.6	5.3	6.0	5.4	6.5	6.2

Further reading

Research reports:
Herweg, K. and Stillhardt, B. 1999 / Krauer, J. 1988

Paper:
Hurni, H. 1989b

Thesis:
Haileselassie Berhanu. 1989

Land Use and Crop Production

Afdeyu is located in the *Kebesa* zone (> 2000 m asl, SCRP: *Weyna Dega*). Table 17 lists the parameters for crop, crop yield and biomass production with the respective data source files:

Table 17: Land use and crop production in Afdeyu: type of data collected, duration of collection and technique of measurement

Parameter	Device / method	Availability in database*	Data source file (primary database)**	Resolution and frequency of data collection
Crop type and crop cover in %.	Weekly observation at different sample locations	01.07.1984 - 31.12.1998	afyycavc.dbf	Weekly
Yield (grain, straw, biomass)	Analysis of different sample locations, test plots and experimental plots	01.07.1984 - 31.12.1989	afyycaha.dbf	Seasonally, during harvest
Sowing date, ploughing date, use of fertiliser, crops of the last two periods	Observations and interviews	01.07.1984 - 31.12.1989	afyycaha.dbf	Weekly / seasonally

Notes: *Not all data collected are available in a digital format.

**In the file names, the letters "af" stand for the station name (Afdeyu), "yy" for year, and the other four letters identify the content of the respective file (e.g. filename af87caha.dbf = Afdeyu / 1987 / catchment harvest).

Catchment Land Use

The size of the hydrologic catchment is 177.2 ha, determined by Burtscher in 2000. Predominant crops are barley and wheat which cover around 60 % of the total cropland. Conditions in Afdeyu do not allow two cropping seasons.

According to Freweini Negash and Helen Habte (1999) different types of crop rotation cycles are practised in Afdeyu:

- *Tsigie*: wheat / barley / one year fallow
- *Kerim*: barley / wheat / one year fallow
- *Salsien*: mixed cropping (barley and wheat) / maize / faba bean (horse bean) / one year fallow
- Intercropping: Irish potato with cowpea (black eyed peas)

Field preparation in general is by contour ploughing. However a different approach is used after fallowing, as described in Freweini Negash and Helen Habte (1999): the first ploughing (*sito*) takes place in September along contours to increase infiltration of water and air. In November, the fields are ploughed along the slope (*aimi*) to mix the soil. In January, the third ploughing (*teslas*) is done again along contours, followed by another ploughing in May (*migunbut*). This last ploughing is along the slope and in wider rills also along the contours to get a chessboard-like pattern.

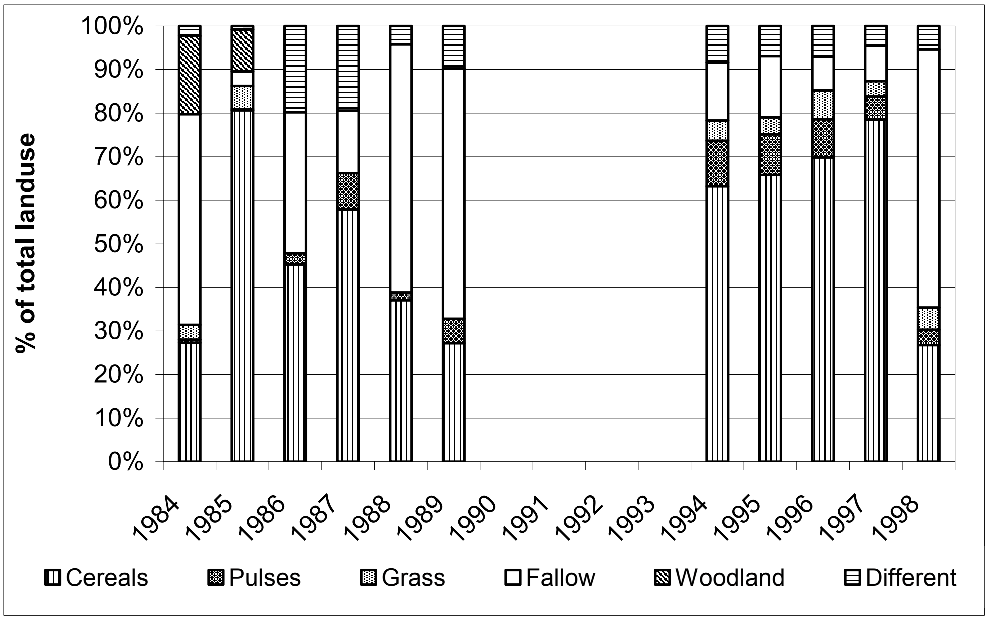


Figure 21: Land use in % of total cultivated area in 1984 - 1998. Note: see Table 18

Results of the land use distribution analysis between 1984 and 1998 are given in Figure 21 and Table 18. The land use pattern of 1994 to 1998 can be found in the Annex. There was only a low quality map as basis for mapping. A more detailed analysis for the years 1994 to 1998 can be carried out by combining the digital terrain model with the land use maps of the Afdeyu research station area.

Table 18: Land use in % of total cultivated area in 1984 - 1990 and 1994 - 1998.

	Cereals	Pulses	Grass	Fallow	Woodland	Different
1984	27.3	0.7	3.4	48.3	17.9	2.3
1985	80.6	0.3	5.3	3.4	9.6	0.8
1986	45.3	2.6		32.4		19.8
1987	57.8	8.4		14.3		19.4
1988	37.1	1.8		57.1		4.2
1989	27.1	5.6		57.2		9.7
1994	61.2	10.1	4.5	12.9	0.0	8.1
1995	63.8	9.0	3.8	13.6	0.0	6.7
1996	67.7	8.4	6.4	7.5	0.0	6.8
1997	76.6	5.1	3.5	7.9	0.0	4.4
1998	26.0	3.4	5.0	57.6	0.0	5.2

Note: It is not known, what type of land use create the remarkable percentage in the category "Different", but it includes the irrigated area used for vegetable production and most probably also woodland was summarised in this category from 1986 onwards.

Crop Yield and Biomass Production

Long-term monitoring (over more than one decade) of seasonal and annual crop yield and biomass production in the same research catchment is a unique and rare database for observing the performance of agricultural production in many ways. It allows the science-based observation of quantitative on-farm measurements of a high-density sampling in a relatively large area, and the results can thus be considered 'typical' for the agro-ecological setting in which the catchment is situated.

Generally speaking, catchment land use mapping is combined with crop yield and biomass sampling in order to produce an estimate of the total seasonal and annual crop yield and biomass production at research catchment level. Obviously, many factors, such as the natural environment (climate, soil, water, crop diseases), the social environment (cultural practices, organisation, production needs and preferences), and the economic environment (farm gate prices, agricultural policies, land tenure, etc. are involved in producing crop yield and biomass as an indicator. An important factor, influencing the data, should be considered when interpreting the results: the methodology chosen. Yield and biomass were analysed in two different settings: on experimental plots and as on-farm yield samples. For detailed EP results see chapter on "Soil Erosion and Soil and Water Conservation".

On-farm yield samples

Grain yield and biomass related to different positions on terraces

Crop yield samples were collected on cultivated land between the existing conservation structures (terraces). The sampling was made randomly for each cropping season on various farmers' cultivated fields in the entire catchment. Three samples per terrace were taken from different locations: one immediately above, one in between, and one immediately below the conservation structure ("bund"). Samples taken between the conservation structures represent a greater area while those taken immediately above or below the structures represent only a narrow strip of 1 to 2 m width.

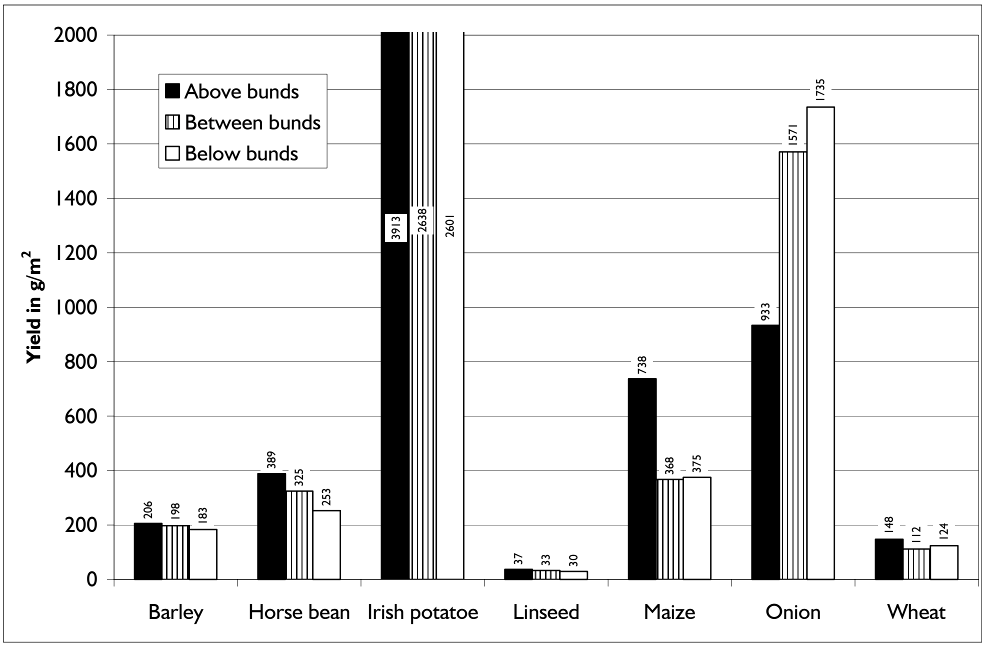


Figure 22: Yield on different sites on conserved land (1987 - 1998). Numbers in or above columns indicate mean yield [g/m^2].

The result of on-farm yield data related to its positions on terraces is shown in Figure 22. The graph shows the impact of conservation structures on production. It should be kept in mind that the area between the structures is larger than the area above and below the structure, respectively. Additional information to this study, such as soil depth and crop type, can be found in the primary database.

With the exception of onions the yield is lowest in the zone below the bunds. This fact is probably due to two processes:

- decreased nutrient level in the soil caused by a loss of topsoil and
- moisture stress caused by a diminution in effective water storage volume (low soil depth).

Table 19: Mean yield [g/m^2] per crop (1984 - 1998, Mayketin catchment, Afdeyu)

	Barley	**Wheat**	**Irish potato**	**Onion**	**Horse bean**	**Linseed**	**Maize**
a	206	148	3913	933	389	37	738
b	198	112	2638	1571	325	33	368
c	183	124	2601	1735	253	30	375
n	44	31	11	8	3	11	3

Note: a = above / b = between / c = below conservation structures. n = Number of samples

The effect of diminishing topsoil in the upper zone of the conservation structure, and the resulting lower plant nutrient capacity have not yet been systematically analysed.

Further reading

Research Reports:
Bono, R. and Seiler, W. 1984b / Erni, T. 1983 / Galizia, M. 1986 / Kappel, R. 1996 / Krüger, H.-J. et al. 1997 / Ritler, A. 1997 and 1999 / Schläfli, K. 1985 / Thomas Tolcha. 1991 / Yohannes G/Michael. 1988

Manuals:
Herweg, K. 1996 / Hurni, H. 1986

Thesis:
Burscher, R. 2000 / Freweini Negash, Helen Habte, 1999 / Yohannes G/Michael. 1992

Maps:
Hurni, H. 1995

Soil Erosion and Soil and Water Conservation

Surface flow (runoff, river discharge) and eroded material (soil loss, suspended sediment yield) are two of the main variables continuously monitored in all SCRP research stations. They are measured on four different scales:

- Micro-plots (MP, 1 x 3 m)
- Test plots (TP, 2 x 15 m)
- Experimental plots (EP, 6 x 30 m)
- Research catchment level (river gauging station)

In this publication, the term "runoff" is used synonymously with overland flow measured on plots. On catchment level, the term "river discharge" is used for the volume of water passing the gauging station at the outlet of the catchment. The term "soil loss" is used for the amount of sediment moving from the plots into the collection tanks. The term "sediment yield" is used for the suspended sediment passing the gauging station.

Based on an analysis of monthly and annual data, this chapter gives information about soil erosion in the SCRP research catchment. For more detailed results, a storm-based analysis would be required, but this is not the subject of the present report.

It should be noted that extrapolation of the information without appropriate model or background knowledge of the research methodology may lead to false conclusions.

Incomplete years are excluded from the calculated annual values. Nonetheless, all plausible monthly values are included to determine monthly means. Usually the first year of measurement and the period between 1992 and 1993 are not included in the analysis.

Table 20 lists the availability of data in the primary database and the devices and frequencies of data collection.

Table 20: Soil erosion and conservation in Afdeyu: type of data collected, duration of collection, and technique of measurement

Parameter	**Device / method**	**Availability in database***	**Data source file (mainly primary database)****	**Resolution and frequency of data collection**
Soil loss and runoff	Micro-plot (MP, size: 1x3 m) measurement in plot tanks	01.01.1988 - 31.12.1990	afyyslpl.dbf	plot emptying periods
Soil loss and runoff	Test plot (TP, size 2x15 m) measurement in plot tanks	01.01.1988 - 31.12.1998 and 01.07.1984 - 31.12.1998	afyyslpl.dbf and afyy_a03.dbf	Plot emptying periods
Soil loss and runoff	Experimental plot (EP, size: 6x30 m) measurement in plot tanks	01.01.1988 - 31.12.1998	afplrssr.dbf and afyyslpl.dbf	afrplrssr.dbf: monthly sums afyyslpl.dbf: plot emptying periods
Amount and intensity of rainfall	Pluviometer/Pluvio-graph (monthly chart rolls)	01.07.1984 - 31.12.1998	afyyplre.dbf***	Periods of constant intensity of rainfall
Erosivity	Calculation on basis of energy and duration of rainfall	01.07.1984 - 31.12.1998	afyy_a03.dbf	Individual storms***
Yield (grain, straw, bio-mass on EP)	Field samples (on fixed and random locations)	01.07.1984 - 31.12.1998	afyycaha.dbf	Weekly, seasonally
Discharge	River station	01.07.1984 - 31.12.2000	eryyrsrd.dbf	Permanent measurement (chart rolls)
Sediment yield	River station	01.07.1984 - 31.12.1998	eryyrsrd.dbf	10-minute intervals as long as water is classified as "brown"

Notes: *Not all data are collected and available in a digital format, especially for 1992 and 1993 no data exist.

**in the file names the letters "af" stand for the station name (Afdeyu), "yy" for the year, the other four letters identify the content of the respective file (e.g. filename af87plre.dbf = Afdeyu / 1987 / pluviograph rainfall erosivity).

***This file contains the amount of rainfall for each interval of constant intensity within the same rainfall event. These amounts are summarised as storm values for further analysis. Definition of a storm: the minimum amount of rainfall must be 12.5 mm; one event must be separated from the next or the previous one by at least 6 hours.

Annual and Monthly Test Plot Results

In 1984, four test plots were established in Afdeyu where soil loss and runoff were measured in plot tanks. Soil type for all plots according to Bosshart (1997) is Cambisol, other sources characterise it as Lixisol. The following conditions are represented on the four plots:

TP 1: Slope is 31 % and the vegetation cover is grass

TP 2: Slope is 2 % and the plot is covered with annual crops

TP 3: Slope is 10 % and the plot is covered with annual crops

TP 4: Slope is 65 % and the plot is partly covered with rock outcrops and bare soil, partly with grass

Annual Data of Test Plot Results

Figure 23 shows the box plots of the annual soil loss on the different test plots. Table 21 lists the crop sequence, runoff, and soil loss on the different test plots. For more information see chapter on "Concept and Methodology".

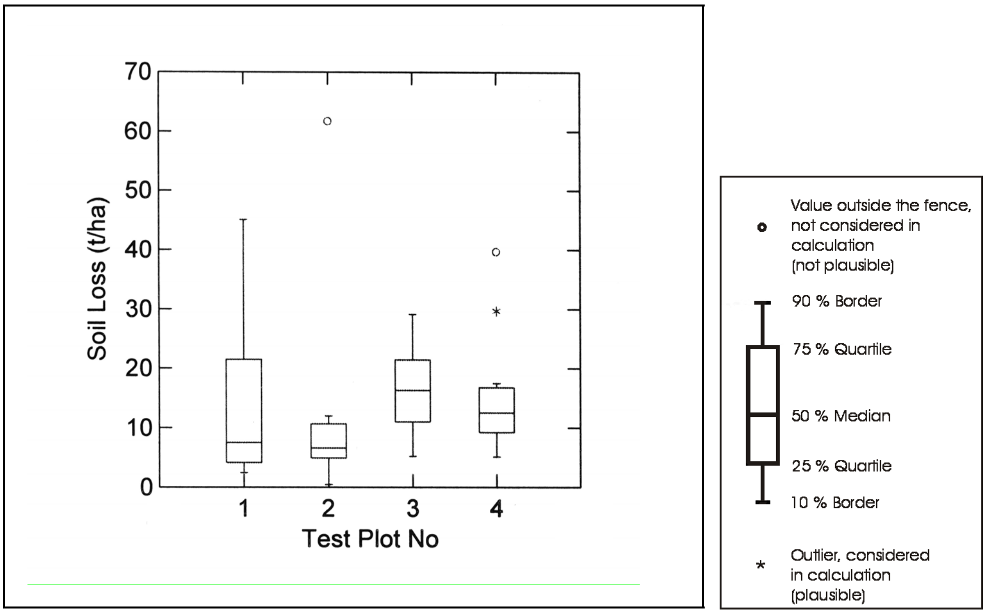


Figure 23: Median annual soil loss on test plots (1985 - 1998, Afdeyu)

Interpretation of the box plots leads to the following conclusions: There are only two plots permanently under crop rotation (annual crops) that can directly be compared: TP 2 and TP 3. The median as well as the mean of the annual soil loss is higher on the steeper plot (TP 3) than on the flatter TP 2.

The mean soil loss on TP 1 (covered with grass) is not high, but shows a high variability. This could be the effect of either non-permanent vegetation cover or of overstocking. The soil loss on TP 4 is not comparable to the soil loss on the other test plots because part of the plot is covered with bare rocks, hence the area exposed to erosion is smaller. Moreover, there is no cultivation (rock and grass) on TP 4, thus the observed soil loss can be described as a result of “natural” erosion (not man-made, in contrast to accelerated erosion) combined with erosion caused by animal tracks crossing the plot.

For a slope of 2 %, the runoff on TP 2 is relatively high. Two years of measurement were excluded because runoff values exceeded than the total rainfall. Probably, run-on was responsible for the high runoff values on this plot.

Table 21: Annual rainfall, erosivity, runoff, and soil loss on test plots (1985 - 1998, Afdeyu)

			TP 1, 31 % slope			**TP 2, 2 % slope**			**TP 3, 10 % slope**			**TP 4, 65 % slope**		
Year	Rainfall [mm]	Erosivity [J/mh]	Crop type	Runoff [mm]	Soil loss [t/ha]	Crop type	Runoff [mm]	Soil loss [t/ha]	Crop type	Runoff [mm]	Soil loss [t/ha]	Crop type	Runoff [mm]	Soil loss [t/ha]
1985	397.7	154.9	gr	90.1	23.5	mz	43.3	10.7	bl	40.5	16.6	gr	40.4	16.0
1986	425.8	201.6	gr	240.5	19.4	mz			li	190.4	29.1	gr	176.7	39.7
1987	384.7	302.7	gr	188.8	38.9	mz			gr	165.9	18.7	gr	150.8	29.7
1988	582.9	491.0	gr	381.4	45.1	fp	322.5	61.7	wt	305.1	26.7	gr	184.8	17.5
1989	258.8	89.2	gr	42.6	2.7	bl	7.9	0.4	wt/bl	55.5	5.2	gr	40.5	5.1
1990	244.1	159.7	gr	80.1	7.5	fl	45.0	4.2	li	87.1	6.6	gr	70.2	15.0
1991	321.5	210.7												
1994	533.9	346.1	n.a.	182.8	3.6	n.a.	245.6	9.0	n.a.	283.6	16.3	n.a.	183.0	7.3
1995	658.0	448.3	n.a.	164.6	5.7	n.a.	69.7	5.1	n.a.	230.5	8.6	n.a.	160.4	11.6
1996	552.0	510.3	n.a.	209.1	9.6	n.a.	272.1	12.0	n.a.	246.9	24.1	n.a.	180.2	12.5
1997	575.0	363.6	n.a.	131.6	4.6	n.a.	100.2	6.6	n.a.	166.2	13.4	n.a.	180.9	9.0
1998	558.1		n.a.	117.4	2.4	n.a.	104.7	4.9	n.a.	135.5	13.6	n.a.	113.6	9.4
Mean	**457.7**	**298.0**		**166.3**	**14.8**		**134.6**	**12.7**		**173.4**	**16.3**		**134.7**	**15.7**
SD	**131.7**	**138.7**		**88.7**	**14.4**		**108.1**	**17.6**		**84.7**	**7.6**		**55.7**	**9.9**
CV	**0.3**	**0.5**		**0.5**	**1.0**		**0.8**	**1.4**		**0.5**	**0.5**		**0.4**	**0.6**
Mean Dev	**87.3**	**109.1**		**99.7**	**13.0**		**108.9**	**21.2**		**79.7**	**7.7**		**60.2**	**9.5**
Rel Dev	**0.2**	**0.4**		**0.6**	**0.9**		**0.8**	**1.7**		**0.5**	**0.5**		**0.4**	**0.6**
Median	**479.9**	**302.7**		**164.6**	**7.5**		**100.2**	**6.6**		**166.2**	**16.3**		**160.4**	**12.5**

Notes:
Erosivity in 1998 only until August. Annual total therefore excluded.
1986 and 1987: runoff was higher than rainfall. Data not analysed.
1991 - 1994: No data because of war and political changes.
n.a.: data not available

In Afdeyu, the second highest values of all SCRP-stations were measured for runoff as % of rainfall, at plot level (see also Table 31). This means that too much of the total amount of rainfall is unavailable for crop production, which is a more serious problem in the area than the relatively moderate erosion rates.

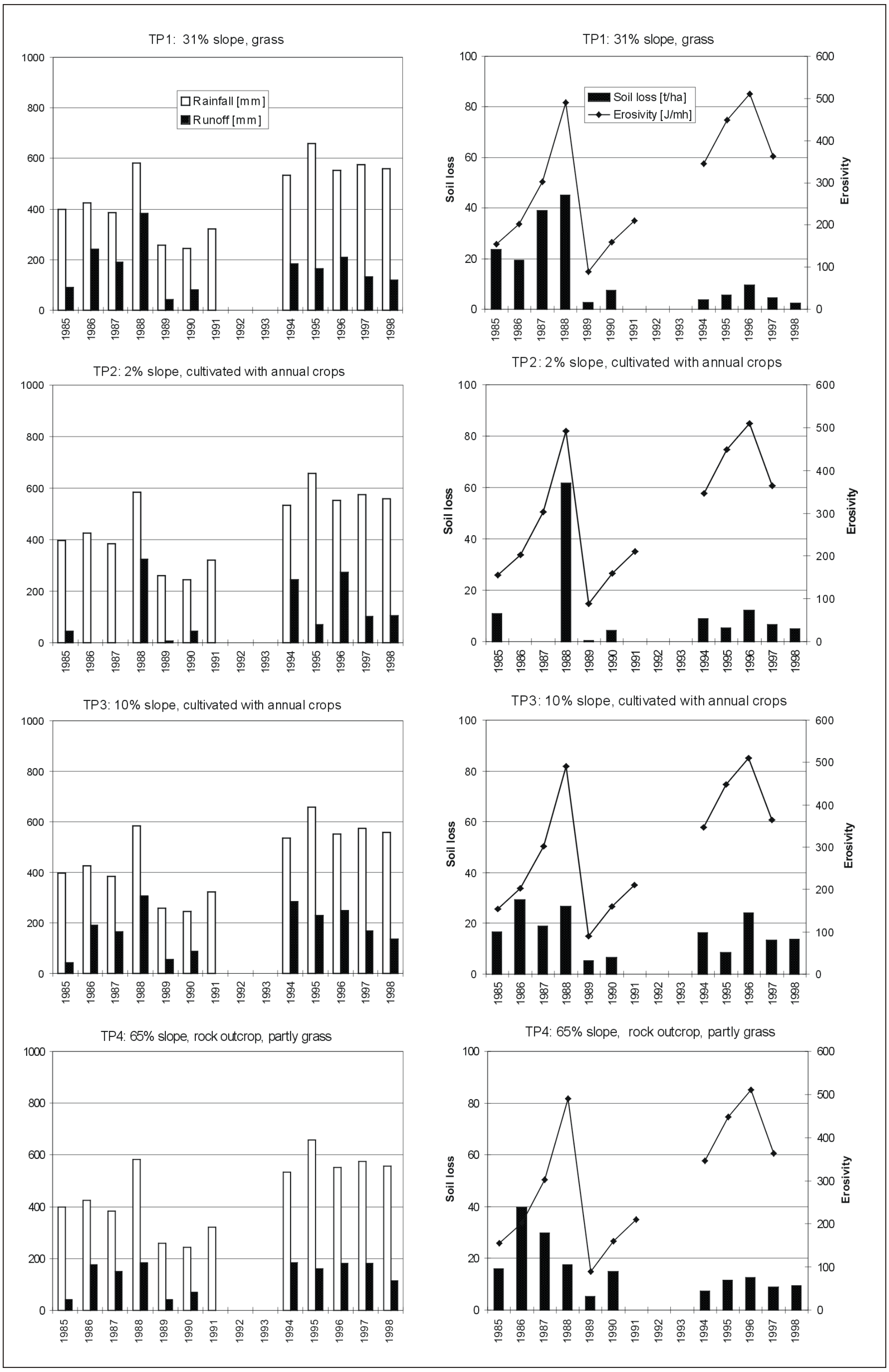


Figure 24: Annual rainfall, erosivity, runoff, and soil loss on test plots (1985 - 1998 Afdeyu). Notes are the same as for Table 21.

Monthly Variation of Test Plot Results

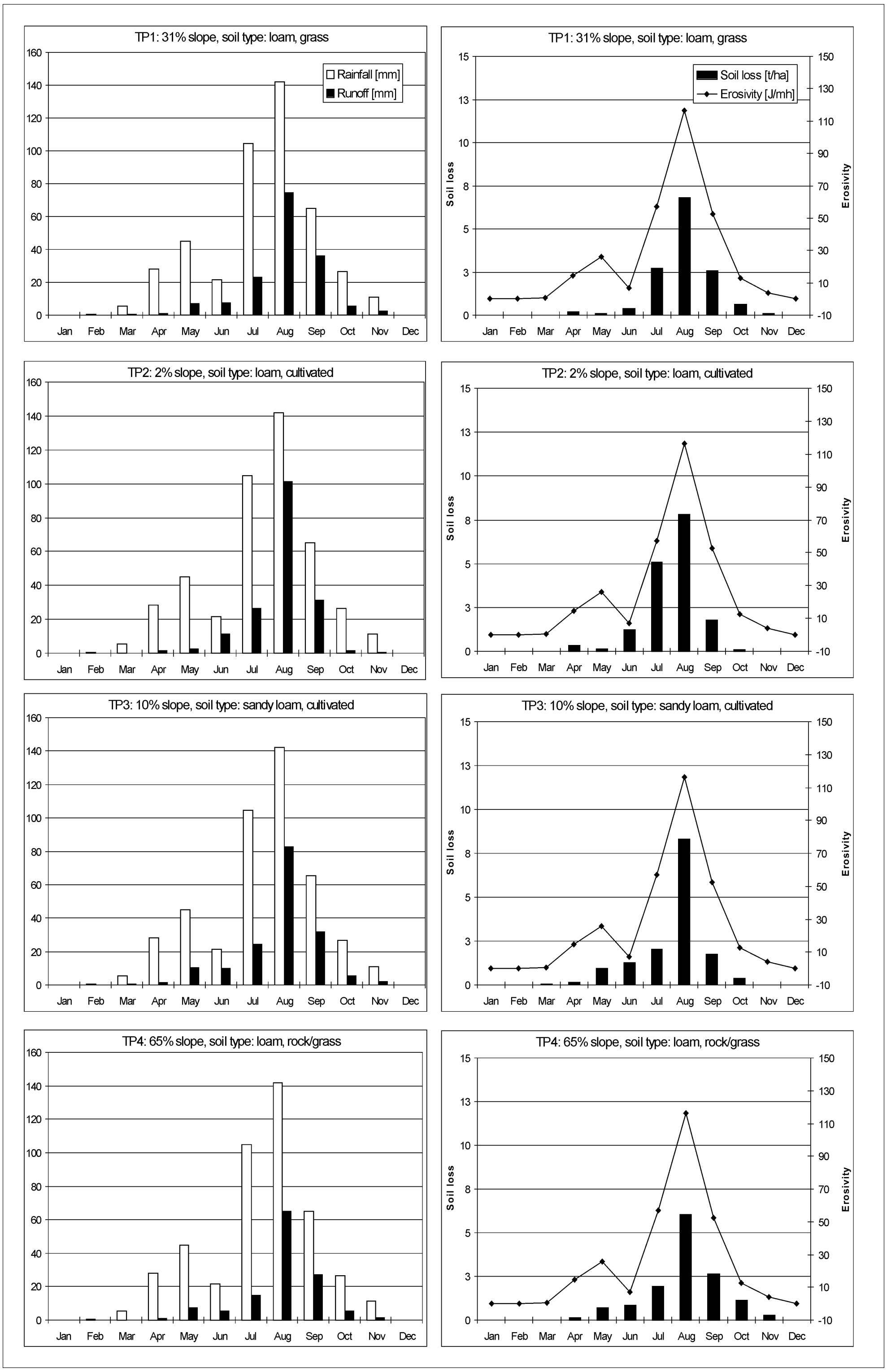


Figure 25: Mean monthly rainfall, erosivity, runoff, and soil loss on test plots (1984 - 1998, Afdeyu)

Table 22: Mean monthly rainfall, erosivity, runoff, and soil loss on test plots (1984 - 1998, Afdeyu)

			TP 1, slope: 31 %, grass		TP 2, slope: 2 %, annual crops		TP 3, slope: 10 %, annual crops		TP 4, slope: 65 %, rocks, grass	
Month	Rainfall [mm]	Erosivity [J/mh]	Runoff [mm]	Soil loss [t/ha]	Runoff [mm]	Soil loss [t/ha]	Runoff [mm]	Soil loss [t/ha]	Runoff [mm]	Soil loss [t/ha]
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mar	5.4	0.7	0.3	0.0	0.0	0.0	0.5	0.0	0.1	0.0
Apr	28.2	14.5	0.8	0.2	1.3	0.3	1.5	0.2	1.1	0.2
May	44.9	26.0	7.1	0.1	2.6	0.1	10.4	1.0	7.3	0.7
Jun	22.6	6.9	7.5	0.4	11.5	1.2	9.9	1.3	5.5	0.8
Jul	107.7	57.0	22.9	2.7	26.2	5.1	24.4	2.0	14.5	1.9
Aug	148.4	116.5	74.4	6.8	101.1	7.8	82.9	8.3	65.1	6.0
Sep	59.4	52.5	36.2	2.6	31.3	1.8	31.8	1.8	27.1	2.6
Oct	28.5	12.8	5.5	0.6	1.3	0.1	5.2	0.4	5.6	1.2
Nov	12.0	4.0	2.6	0.1	0.4	0.0	2.0	0.0	1.5	0.3
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Annual and Monthly Micro-Plot Results

There were only two micro-plots in Afdeyu. The problems that runoff often exceeded rainfall in the 1990s led to the decision to remove the plots. Both micro-plots were situated on Cambisols or Lixisols, one next to TP 2, the other next to TP 3.

Annual Data of Micro-Plot Results

Table 23: Annual rainfall, erosivity, runoff, and soil loss on micro-plots (1985 - 1990, Afdeyu)

			MP 5, 2 % slope			MP 6, 10 % slope		
Year	Rainfall **[mm]**	Erosivity **[J/mh]**	Crop **type**	Runoff **[mm]**	Soil loss **[t/ha]**	Crop **type**	Runoff **[mm]**	Soil loss **[t/ha]**
1985	397.7	154.9	mz	165.2	14.1	bl	114.4	27.6
1986	425.8	201.6	mz			li	367.4	65.8
1987	384.7	302.7	mz			gr	371.9	16.7
1988	582.9	491.0	fp	491.4	33.4	wt	379.1	44.2
1989	258.8	89.2	bl	43.5	1.9	wt/bl	75.9	3.9
1990	244.1	159.7	fl	189.8	10.9	li	133.4	11.0
Mean	**373.6**	**230.0**		**222.5**	**15.1**		**240.4**	**28.2**
SD	**106.8**	**122.5**		**164.8**	**11.5**		**133.6**	**21.2**
CV	**0.3**	**0.5**		**0.7**	**0.8**		**0.6**	**0.8**
Mean Dev	**84.7**	**95.4**		**134.5**	**9.2**		**132.5**	**17.9**
Rel Dev	**0.2**	**0.4**		**0.6**	**0.6**		**0.6**	**0.6**
Median	**384.7**	**201.6**		**177.5**	**12.5**		**250.4**	**22.2**

Table 24: Mean annual runoff and soil loss on test plots and comparable micro-plots (1985 - 1990, Afdeyu).NB: The mean value of TPs considers only the period comparable with MP measurement and not the entire TP measurement.

	TP 2	MP 5	TP 3	MP 6
Runoff [mm]	104.7	222.5	140.8	240.4
Soil loss [t/ha]	19.3	15.1	17.2	28.2

TP 2 / MP 5 and TP 3 / MP 6 are arranged in pairs. The comparable time of measurement was only 1985 to 1990, with the exclusion of the 1986/87 data for the pair TP 2 / MP 5 due to flooding of the plots. In 1991, the micro-plots were removed. In most years, MP runoff and soil loss values were higher than TP values, with the exception of 1988 on TP 2, due to extremely high runoff. This year distorts the mean. The case that soil loss on longer slopes (15 m) is less than on shorter slopes (3 m) indicates transport-limited conditions, leading to frequent deposition of sediment in diffuse accumulations all over the fields. However, conditions reverse during severe rainfall events.

Monthly Variation of Micro-Plot Results

Table 25: Mean monthly runoff and soil loss on micro-plots (1985 - 1990, Afdeyu)

Month	MP 5, 2 % slope		MP 6, 10 % slope	
	Runoff [mm]	Soil loss [t/ha]	Runoff [mm]	Soil loss [t/ha]
January	0.0	0.0	0.0	0.0
February	0.0	0.0	0.0	0.0
March	0.0	0.0	1.6	0.0
April	0.5	0.1	0.9	0.2
May	0.0	0.0	14.0	0.4
June	0.9	0.0	9.7	1.1
July	65.1	6.3	44.7	9.0
August	45.8	1.7	71.3	7.2
September	5.1	0.1	49.2	6.2
October	1.3	0.0	7.4	0.4
November	0.0	0.0	2.5	0.2
December	0.0	0.0	0.0	0.0

Notes:

MP 5: 1985: Runoff and soil loss in August excluded because runoff >> rainfall
1986: Runoff and soil loss excluded because runoff >> rainfall
1987: Runoff and soil loss excluded because runoff >> rainfall
1988: Runoff and soil loss in September excluded because runoff >> rainfall
1990: Runoff and soil loss in September and October excluded because runoff >> rainfall

MP 6: 1987: Runoff and soil loss in October excluded because runoff >> rainfall

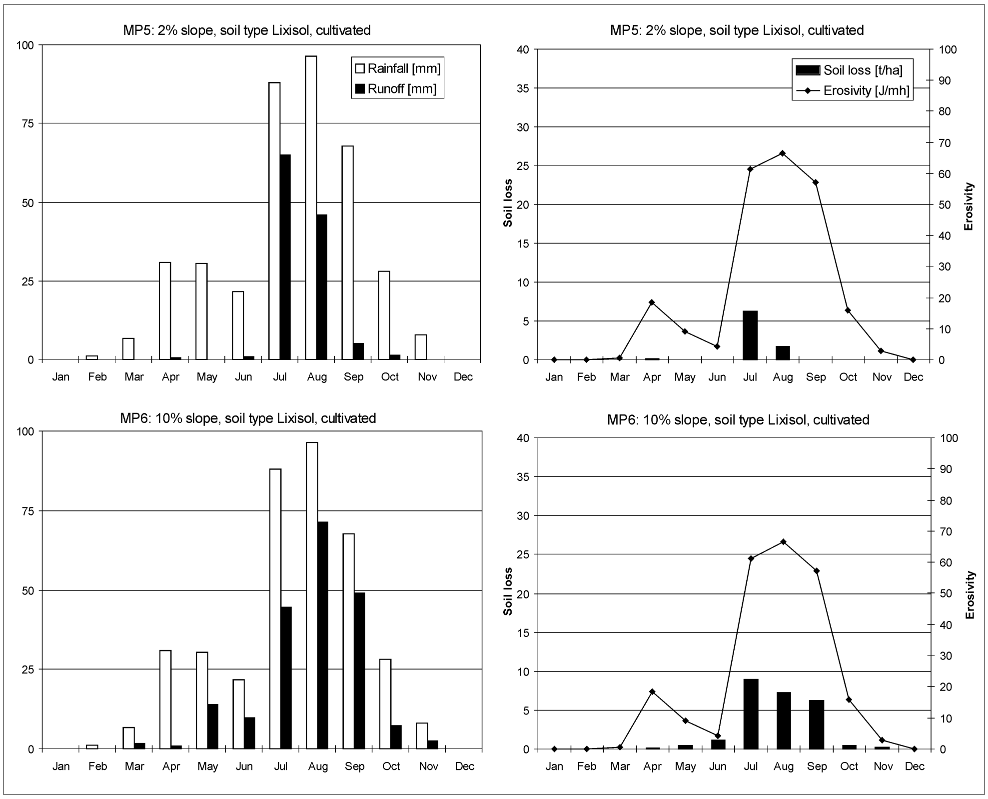


Figure 26: Mean monthly runoff and soil loss on micro-plots (June 1984 - 1990, Afdeyu). Notes are the same as for Table 28

Soil Conservation Experiments on Experimental Plots and Farmers' Fields

Five experimental plots were built in 1988. The measurements of the fifth plot is not included in the following analysis because of its different size. The four experimental plots are situated next to each other on Cambisol/Lixisol on a slope of 31 %. Graded structures were not tested in Afdeyu because water needs to be harvested. On experimental plots the following soil conservation structures were tested versus a control plot with no conservation structures:

- level *double ditch*
- level *Fanya Juu*
- level bund

Annual Runoff and Soil Loss on Experimental Plots

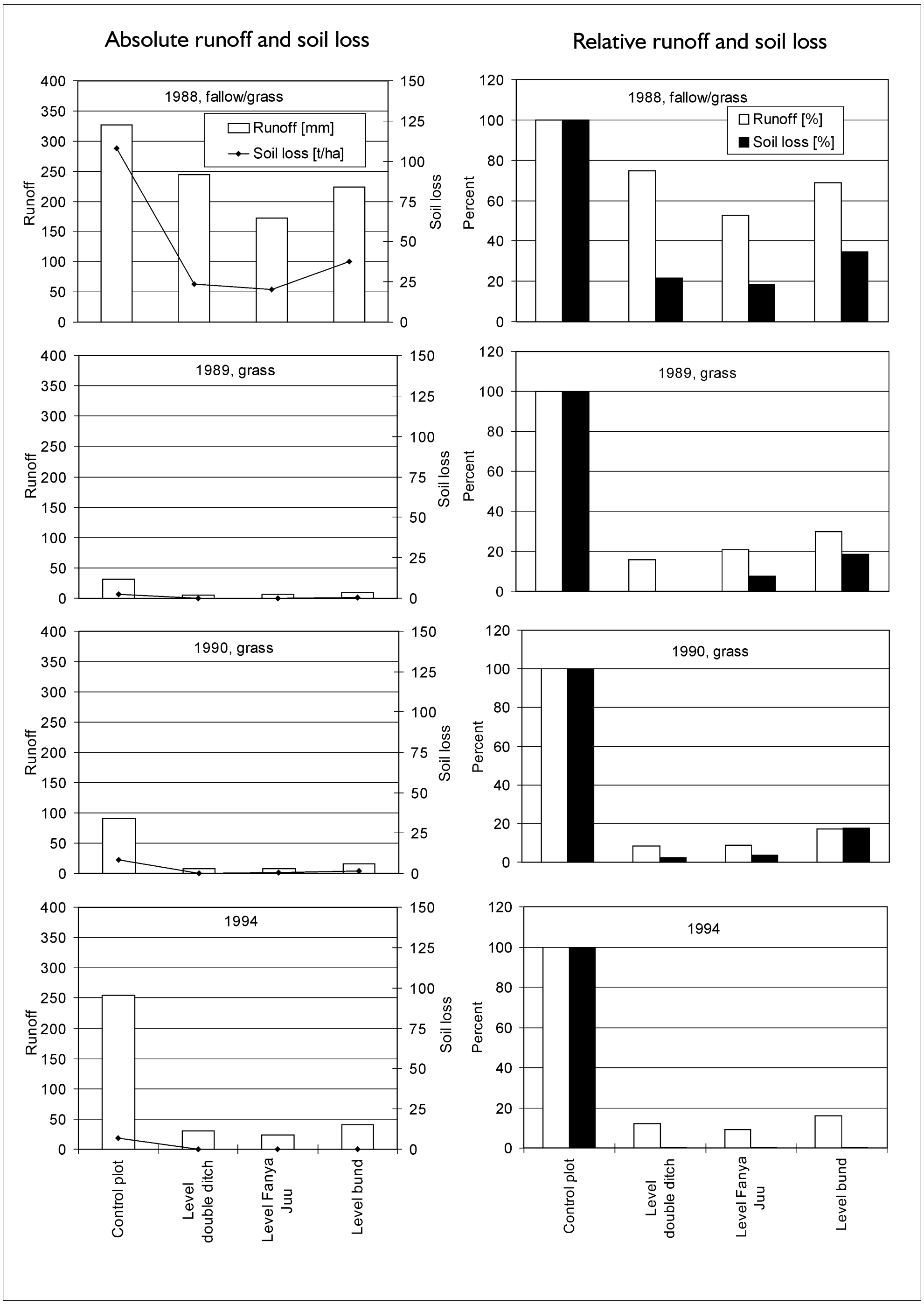
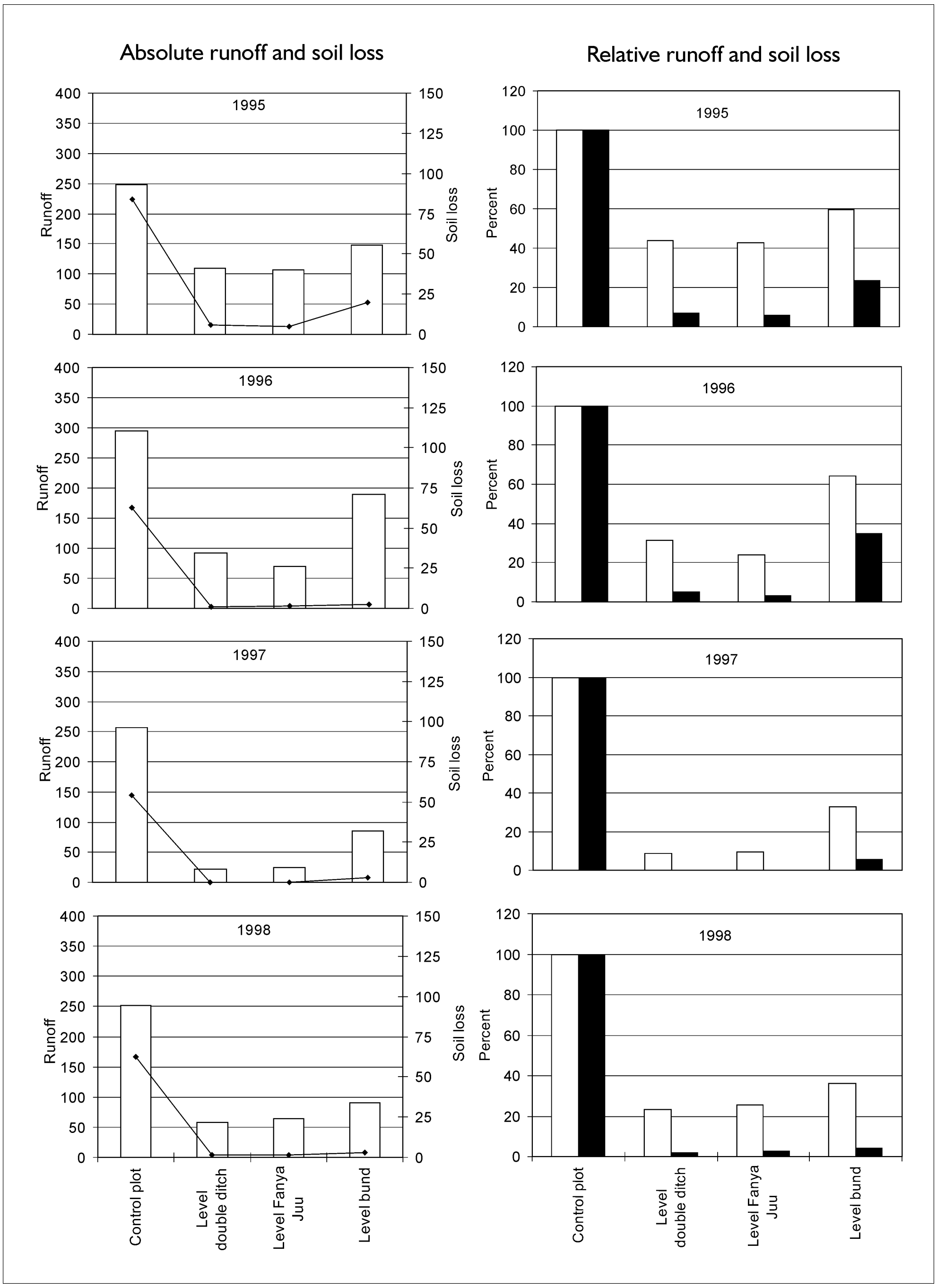


Figure 27: Absolute and relative annual runoff and soil loss on experimental plots (1988 - 1998, Afdeyu). Note: To calculate the relative values of runoff and soil loss, the amount measured on the control plot is set to be 100 % for each year. When comparing different years, please note that the total absolute amount can thus differ considerably!

Figure 27, continued



Note: To calculate the relative values of runoff and soil loss, the amount measured on the control plot is set to be 100 % for each year. When comparing different years, please note that the total absolute amount can thus differ considerably!

The remarkable difference between the total amounts of runoff and soil loss in the late 1980s compared to the results of the 1990s asks for a more detailed analysis. The same problem arises for total rainfall amounts. The high amounts of rainfall (and consequently also of runoff and soil loss) in the second half of the 1990s are probably a result of changes in the global circulation system: the strong El Niño circulation led to high rainfall amounts which are documented also for other parts of eastern Africa.

Table 26: Annual runoff and soil loss on experimental plots (1988 - 1998, Afdeyu)

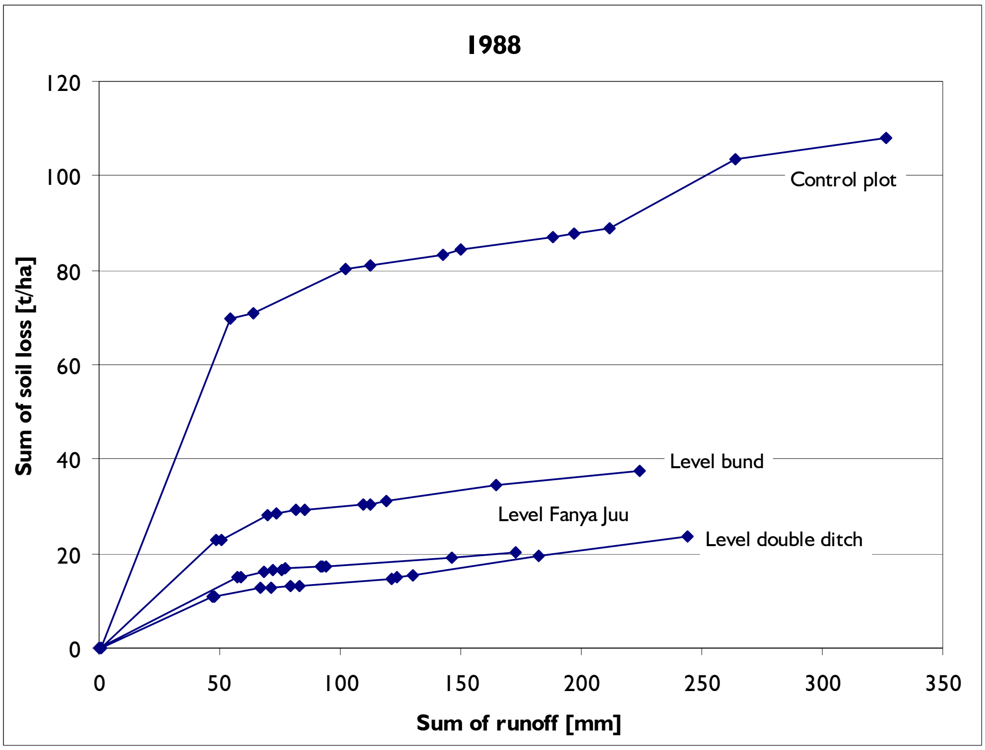
Annual runoff [mm]						
Year	Rainfall	Control plot (3*20 m)	Control plot (6*30 m)	Level double ditch	Level *Fanya Juu*	Level bund
1988	582.9	413.6	326.7	244.4	172.5	224.4
1989	258.8	33.6	31.9	5	6.6	9.5
1990	244.1	65.6	90.8	7.7	8.1	15.7
1994	533.9		254.5	30.8	23.2	40.7
1995	658		248.4	108.7	106.4	148.4
1996	552		294.7	92.6	70.2	189.0
1997	575		257.3	22.0	24.7	84.6
1998	558.1		251.3	58.0	64.1	90.5
Mean	495.4		**219.5**	**71.1**	**59.5**	**100.3**
Annual soil loss [t/ha]						
Year	Erosivity	Control plot (3*20 m)	Control plot (6*30 m)	Level double ditch	Level *Fanya Juu*	Level bund
1988	491	65.5	108.1	23.6	20.1	37.6
1989	89.2	3.0	2.7	0.0	0.2	0.5
1990	159.7	10.4	8.6	0.2	0.3	1.5
1994	210.7		6.9	0.0	0.0	0.0
1995	346.1		84.0	5.7	4.7	19.7
1996	448.3		62.6	3.3	1.9	21.9
1997	510.3		54.1	0.0	0.0	3.1
1998			62.5	1.2	1.7	2.7
Mean	322.1		48.7	4.3	3.6	10.9

Stormwise Analysis of and Conclusive Remarks on Plot Results

Stormwise Analysis of Experimental Plot Results

The following double mass curves relate summarised soil loss and summarised runoff for all years. It should be kept in mind, that scales differ for single years.

On the X-axis runoff is cumulated, on the Y-axis soil loss. One point represents one measurement on the respective plot. Care must be taken not to compare the plots of the different years directly, as scales are not uniform! In dry years, the total amount of runoff and soil loss is too small to produce a visible picture if uniform scales are taken.



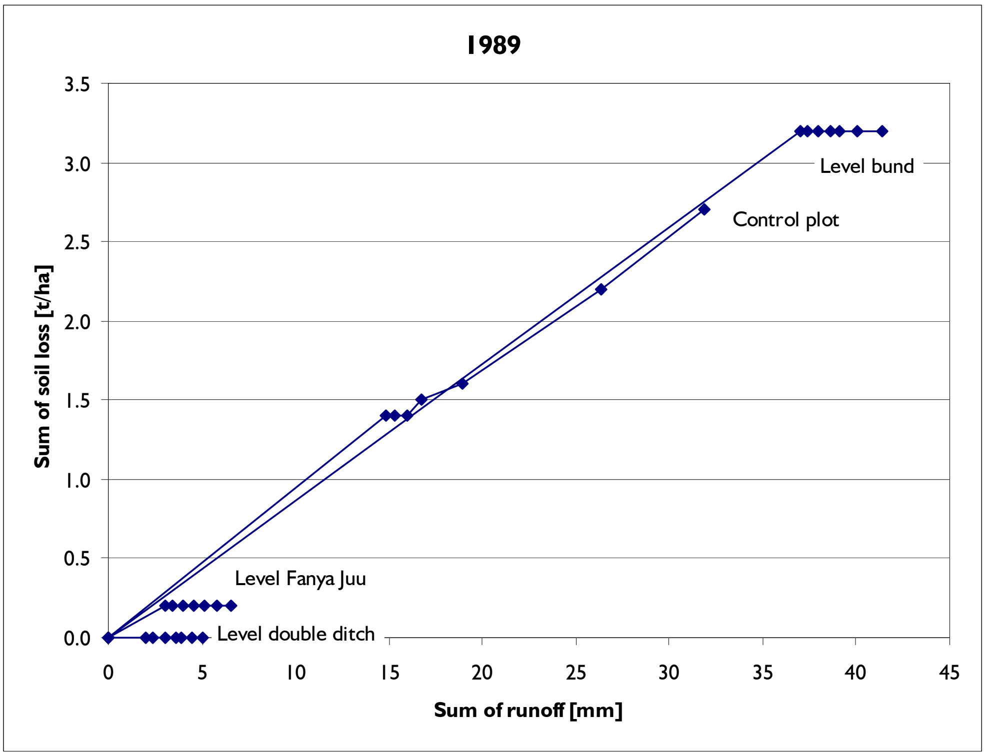
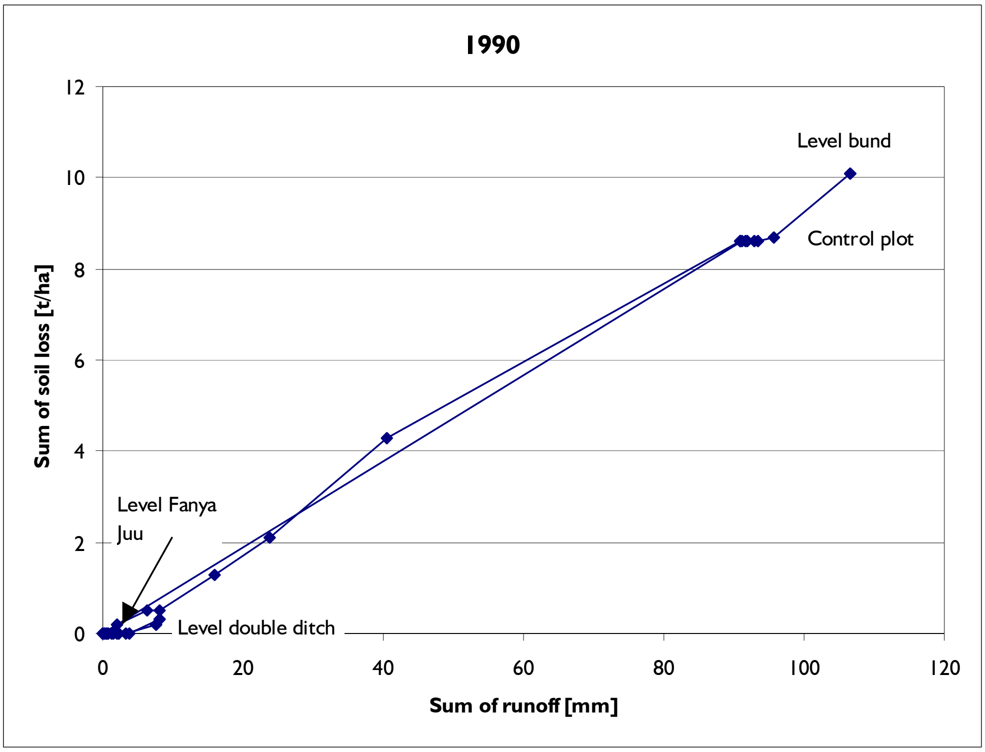
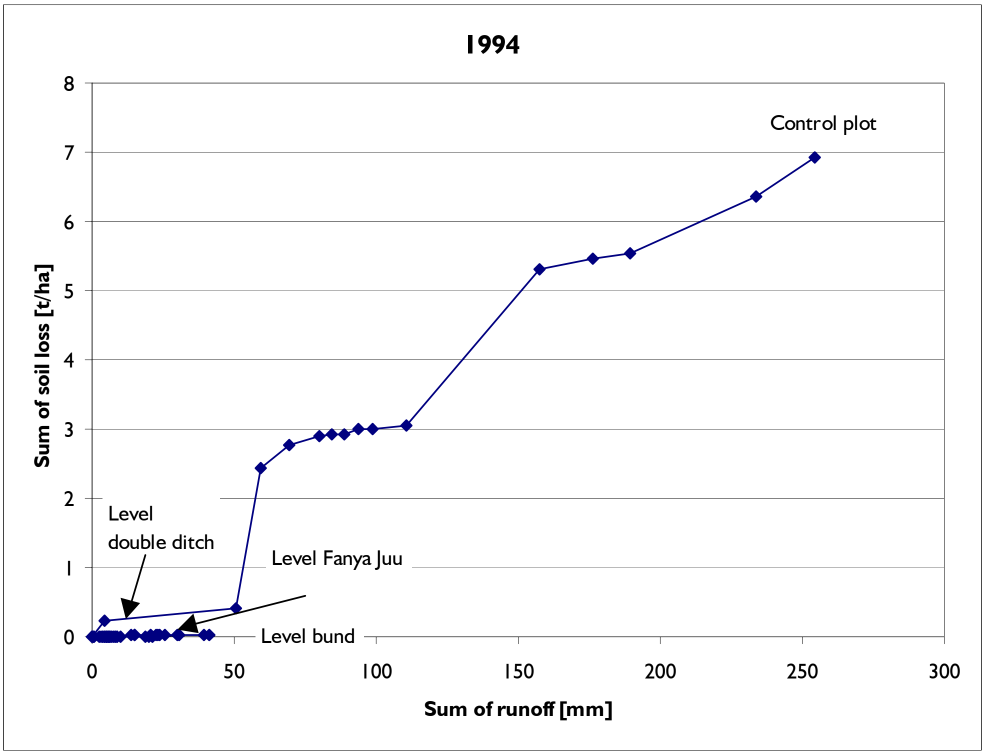


Figure 28: Double mass curves of soil loss and runoff on experimental plots. Please note that the scales differ for different years!

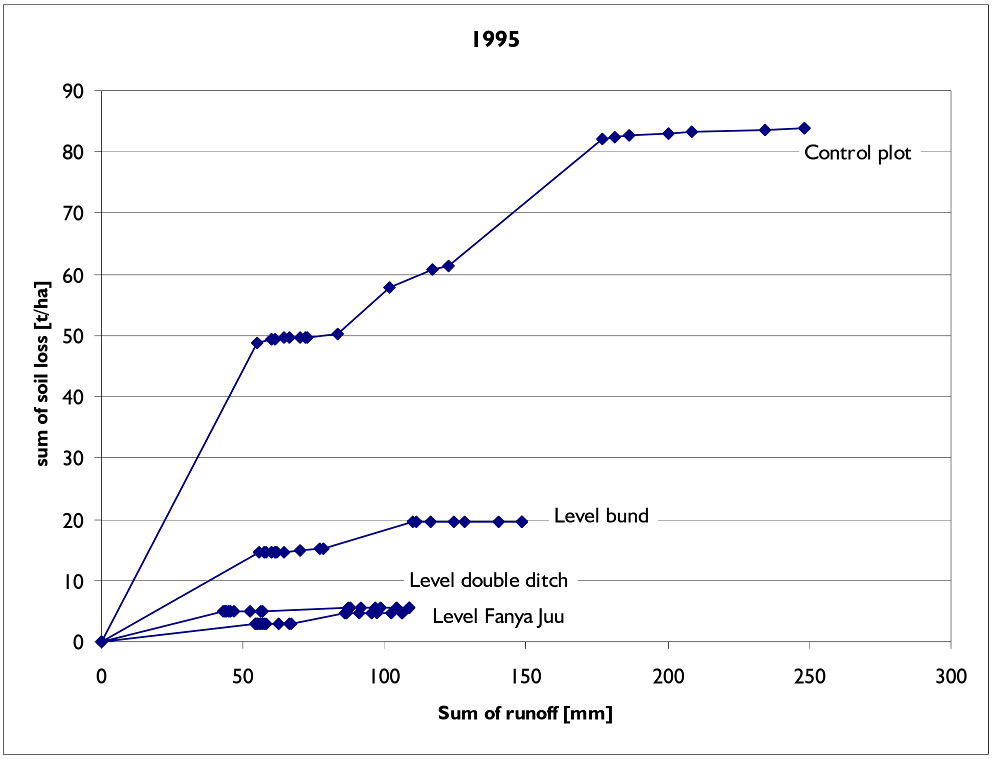
Figure 28 continued

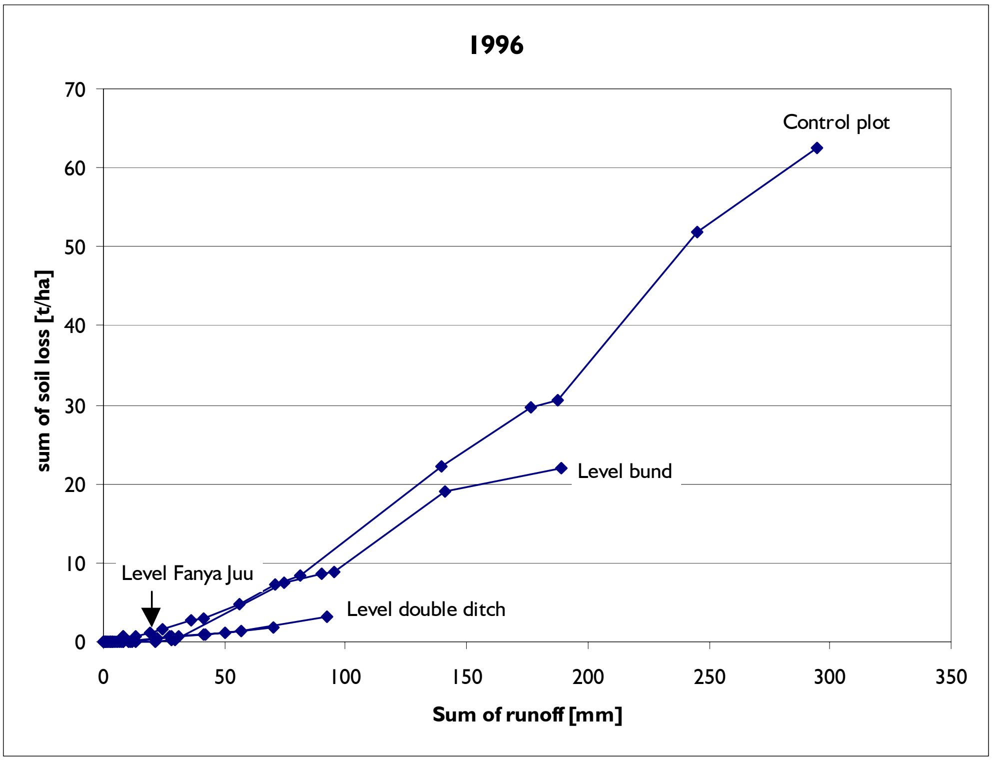




Please note that the scales differ for different years!

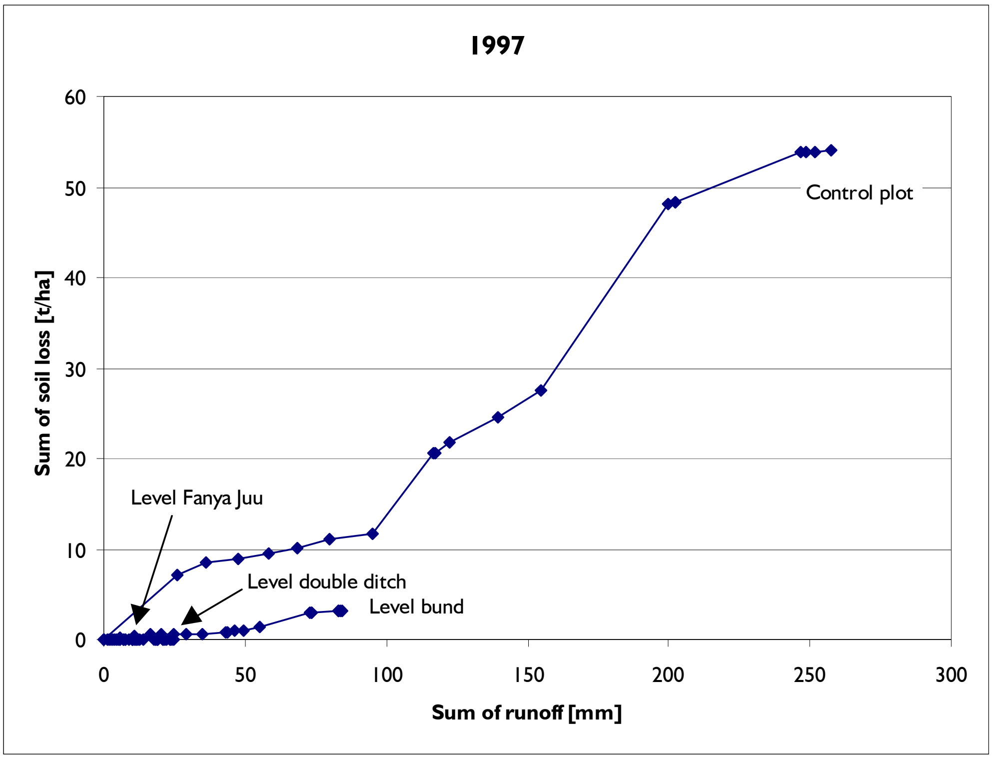
Figure 28 continued

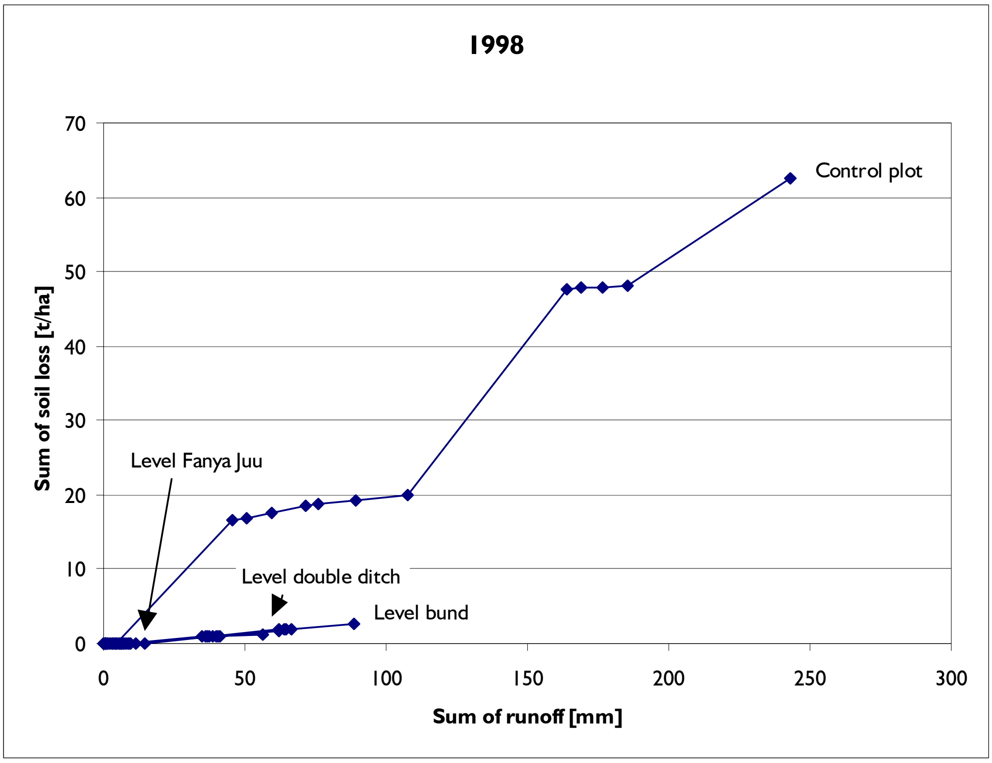




Please note that the scales differ for different years!

Figure 28 continued





Please note that the scales differ for different years!

Generally, the control plot shows the highest values of runoff and soil loss. Only during the two dry years 1989 and 1990 the loss from the plot with level bund was higher than that from the control plot. But the total amount is very small and the difference between the results of the two plots is negligible.

Table 27: Ranking of the different soil conservation measures in different years, showing the effects of a certain SWC structure on erosion. If two absolute amounts were similar, the same rank was set.

Year	Control plot		Level bund		Level *Fanya Juu*		Level double ditch	
	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff
1989	3	3	4	4	2	2	1	1
1990	3	3	4	4	1	1	2	2
1994	4	4	1	3	1	2	1	1
1995	4	4	3	3	1	1	2	2
1996	4	4	3	3	1	1	2	2
1997	4	4	3	3	2	1	1	1
1998	4	4	3	3	2	2	1	1
Total	**26**	**26**	**21**	**23**	**10**	**10**	**10**	**10**
Rank	**4**	**4**	**3**	**3**	**1**	**1**	**1**	**1**

NB: Rank 4 indicates that the respective plot showed in a certain year the highest measured amount of soil loss or runoff compared to the other plots, rank 1 the lowest.

In Table 27, soil loss and runoff are ranked for each year. The highest amount (of soil loss or runoff) corresponds with the highest rank. These ranks are summarised in the row "Total" and again ranked. The result shows that in the environment of Afdeyu level bund is less effective than the other two measures. Compared with the control plot level bund also reduces soil loss and runoff, but compared with the other two measures level bund is less effective. Level double ditch and level *Fanya Juu* reduce soil loss and runoff to a similar amount (both reach a total of 10 points for soil loss as well as for runoff). There are no visible differences in between the two measures, not even on the individually scaled double mass curves (see Figure 28). Taking into consideration that the loss of cultivable area under *Fanya Juu* is 17 %, and under double ditch 24 % (Semere Zaid, 1998), *Fanya Juu* seems to be more promising, at least from a technical point of view. It is important to note that one bund occupy only 14 % o the cultivated area.

Comparing the effect of wet and dry years on erosion hazards level *Fanya Juu* and level double ditch do not show significantly different results. Possibly, the analysis of single events will lead to further classification.

According to Awet Berhe and Bereket Mebrahtu (1999), about 98 % of the cultivation land at Afdeyu is conserved with mechanical SWC structures. About 75 % of the farmers state that contour bunds are their favourite method. The main reason for their preference is that the loss of productive area (14 %) is smaller than with other proposed measures like *Fanya Juu* (17 %) or level double ditch (24 %). Additional costs and lack of knowledge are other frequently mentioned reasons. The same publication stated that more than 1/3 of the farmers constructed SWC measures to conserve soil and water, and another 20 % did it to increase crop production.

Stormwise Analysis of Test Plot Results

Figures 29 to 32 show the effect of single storms on erosion processes on test plots. In a first step, the events are ranked according to soil loss. Then, all parameters are expressed as percent of the annual total and summarised. 1988 is taken as example because it was the year with the highest total amount of rainfall measured. It therefore shows the highest soil erosion dynamics during this period:

The event causing the highest soil loss on TP 1 and TP 2 was on the 29 July, 1988 (emptying date of the plots). For TP 3 the rainfall event causing the highest soil loss was on the 9th of August, for TP 4 it was on the 13th of September. In each case heavy rainfall occurred on the day before plots were emptied. All three events had a total of more than 50 mm of rainfall and the erosivity was between 35 and 100 J/mh, and are therefore classified as storms with very high or extreme erosivity.

For the period between 1985 and 1990 it was found that on test plots, on average, only 15 % of the annual rainfall events produce about 70 % of the total annual soil loss.

The rocky outcrop of the steep TP 4 reduces the area covered with soil. This fact was most probably responsible for the small amount of total annual soil loss from this plot. It is also worth mentioning that TP 4 was not cultivated and therefore the result is representative for erosion hazards on untreated steep slopes.

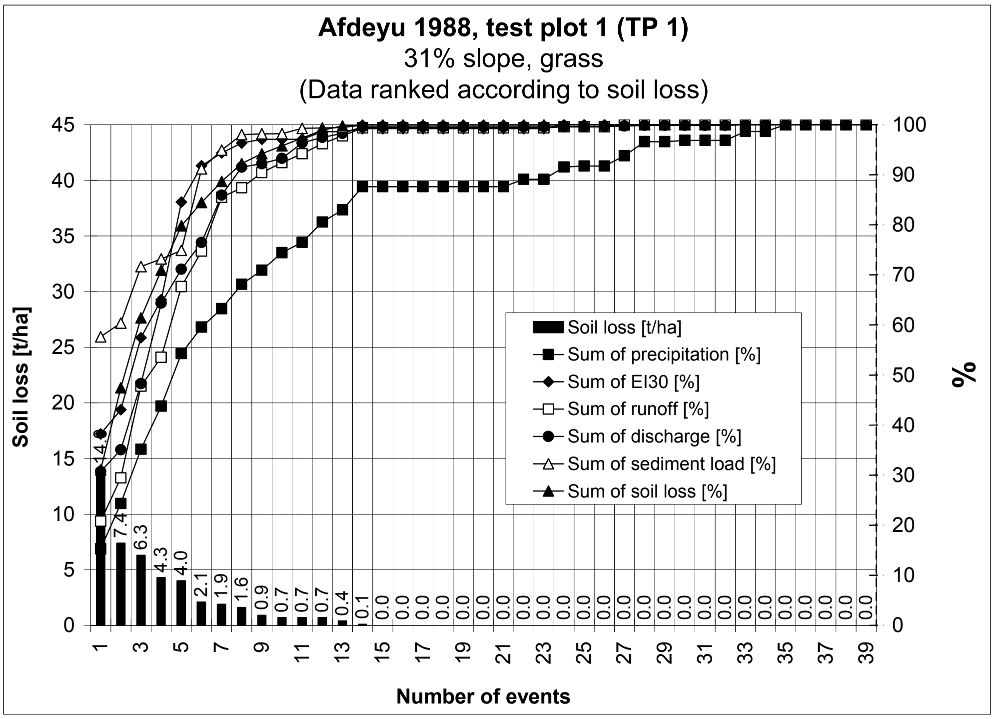


Figure 29: Sum curve of rainfall, runoff, erosivity, soil loss, catchment discharge, and sediment yield on TP 1 in 1988

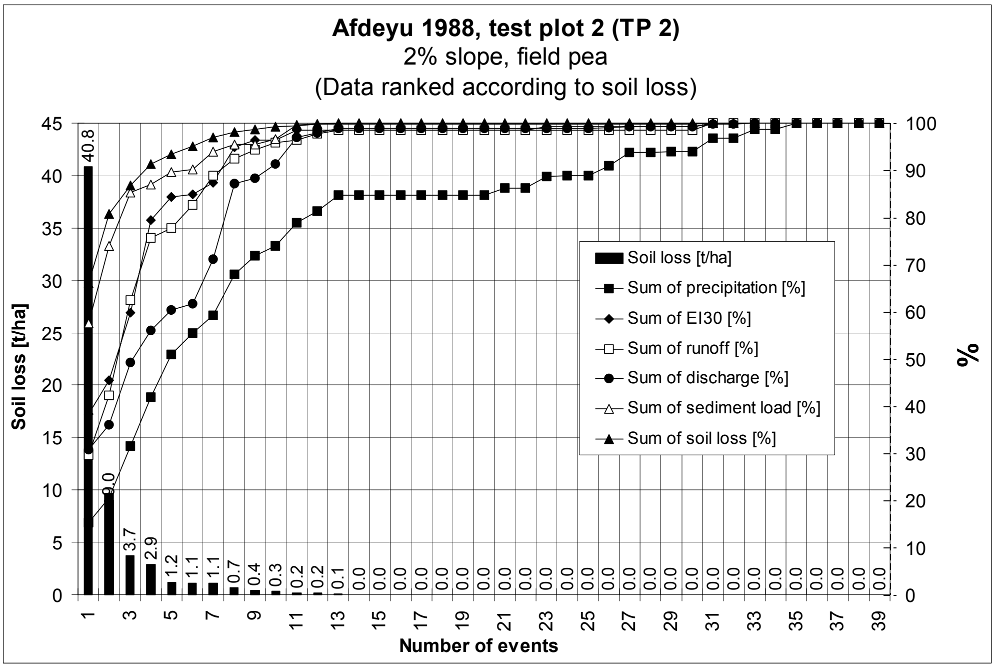


Figure 30: Sum curve of rainfall, runoff, erosivity, soil loss, catchment discharge, and sediment yield on TP 2 in 1988

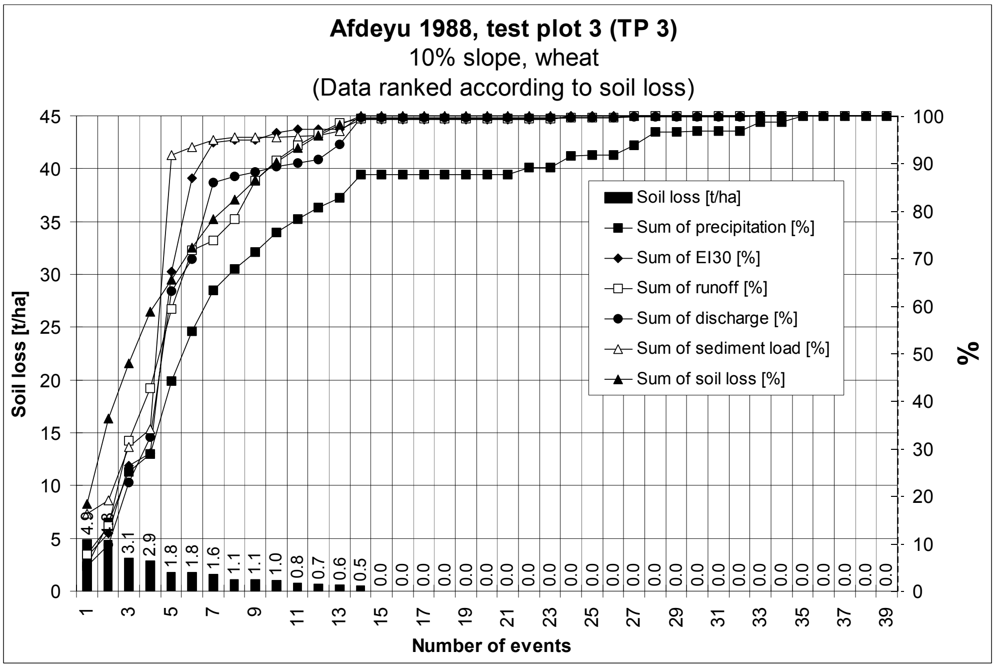


Figure 31: Sum curve of rainfall, runoff, erosivity, soil loss, catchment discharge, and sediment yield on TP 3 in 1988

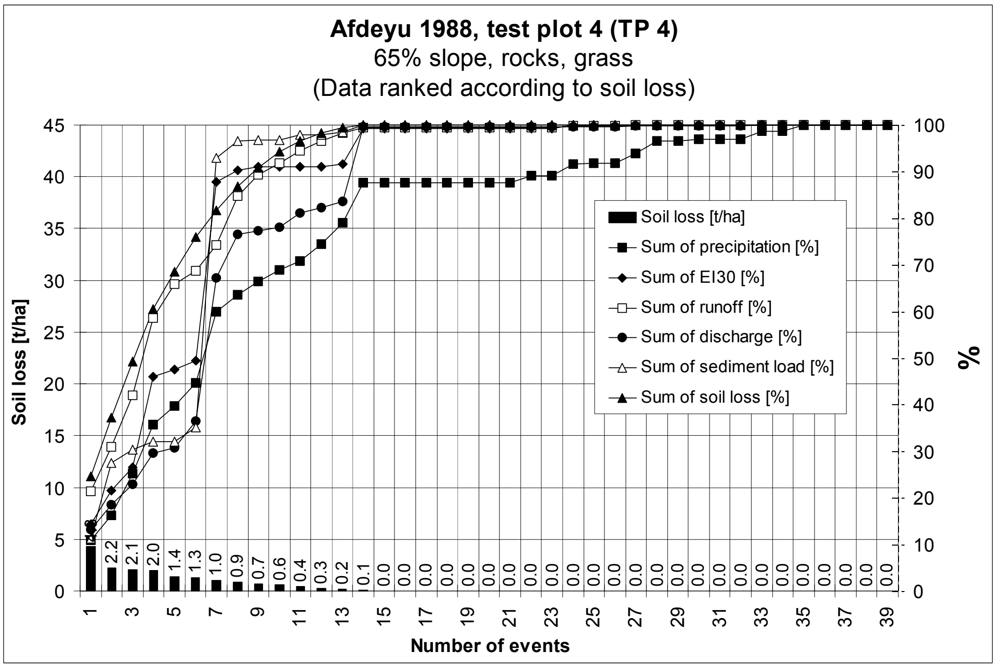


Figure 32: Sum curve of rainfall, runoff, erosivity, soil loss, catchment discharge, and sediment yield on TP 4 in 1988

TP 2 was cultivated with field pea, covering about 50 % of the surface, TP 3 was cultivated with wheat covering about 60 % of the surface. Total annual soil loss on the flatter TP 2 was almost ten times higher than on the steeper TP 3. As mentioned above, it was not the same event causing the highest soil loss on this two plots. The event on the 29th of July, causing the high soil loss on TP 2, was a heavy rainstorm with a total amount of rainfall of 89.1 mm and an erosivity of 187 J/mh. The event causing the highest soil loss on TP 3 was of short duration but of high intensity, and brought only a total of 31 mm of rainfall.

There are various possible explanations for the fact that the rainfall of the 29th of July caused a much higher soil loss on TP 2 than on TP 3:

- On TP 2 weed control (hacking) took place a short time before 29th of July.
- Cover of field peas is not as protective as that of wheat (with comparable percentages of surface cover).

Soil loss and runoff at different plot levels

Different plot (or observation) levels allow different combinations of processes to take place:

Table 28: Comparison of soil erosion processes at different plot levels. (ACED = Assessment of Current erosion Damage, Herweg, 1996)

Level/ Device	Soil degradation processes						
	Erosion					Deposition	
	Rain splash	Sheet flow	Prerill erosion	Rill erosion	Gully erosion	Diffuse accumulation	Concentrated accumulation
*MP	\\\	\\\	///			\\\	
TP	\\\	\\\	\\\	///		\\\	
EP	\\\	\\\	\\\	\\\		\\\	\\\
ACED			\\\	\\\	\\\		\\\
Catchm.	\\\	\\\	\\\	\\\	\\\	\\\	\\\

\\\ frequently observed
/// rarely observed

- Micro-plots (MP, length 3 m; width 1 m): no rills were observed on MPs, indicating that their length seems too short for the formation of rills. The soil loss measured consists of material detached by rain splash and moved by sheet flow. MP results (available until 1990) represent the amount of soil that is moved from an inter-rill area.
- Test plots (TP, length 15 m; width 2 m): besides rain splash and sheet flow, prerills with a depth of a few cm were observed on test plots. At the same time, diffuse accumulations of eroded material occur, which partly refilled the prerills. The TP situation represents for example a terrace between two SWC structures.
- Experimental plots (EP, length 30 m; width 6 m): on the eroded part below the structure, rain splash, sheet flow, prerill and rill erosion may occur. The deposition part above the structure consists of concentrated accumulations. In contrast to TP, the EP represent a situation with a sequence of terraces or SWC structures that intercept runoff and soil transport.
- The assessment of current erosion damage (to estimate the erosion processes on farmers' fields) considers exclusively linear erosion features, such as prerills, rills, and gullies, as well as concentrated deposits.
- The sediment yield measured with hydrometric devices (river gauging station) at the outlet of the catchment is the result of all water erosion processes taking place in the catchment, including erosion and deposition in the river bed itself.

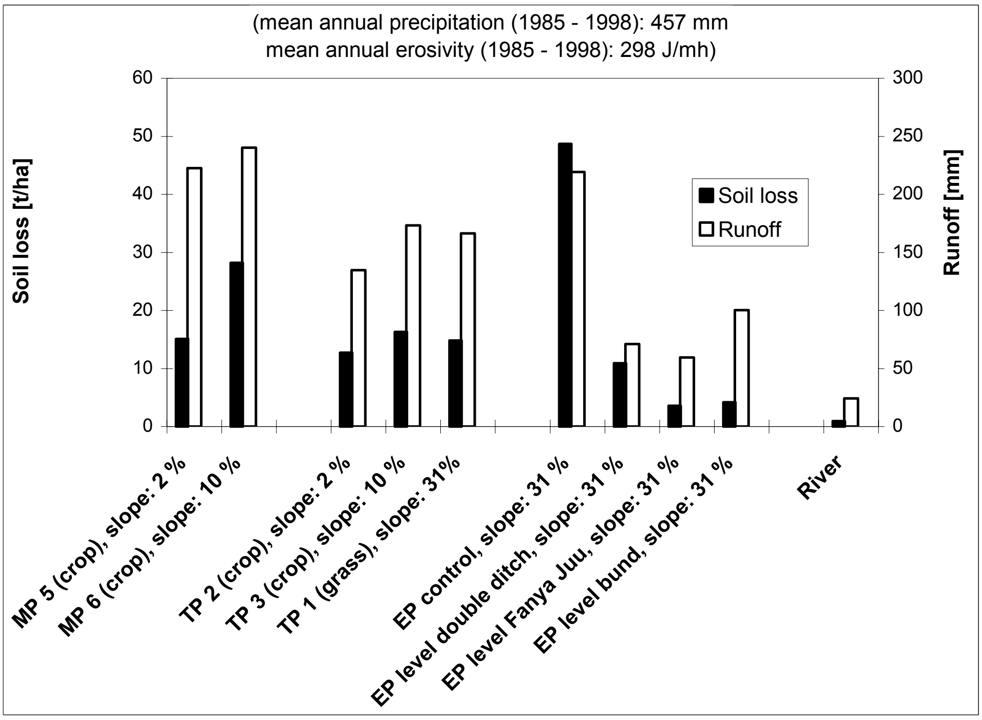


Figure 33: Comparison of soil loss and runoff on the different measurement levels.
Measurement period for Micro plots: 1985 - 1990
Measurement period for test plots: 1985 - 1990 and 1994 - 1998
Measurement period for experimental plots: 1988 - 1990 and 1994 - 1998
Measurement period for the river gauge station:1985 - 1990 and 1994 - 2000

When interpreting Figure 33, it should be kept in mind that plots have a different slope length (MP: 3 m, TP: 15 m, EP: 30 m) and three EP are treated with different SWC measures.

As discussed earlier the comparison of MP and TP shows that soil loss and runoff on MP are higher than on TP. This indicates transport-limited conditions and diffuse accumulation of eroded material. However, if slope length increases to 30 meter (EP control plot), rill erosion and entrainment seem to increase soil loss considerably. An artificial reduction of slope length, as it is achieved on the EPs treated with SWC measures, suggests an effective reduction of both, runoff and soil loss.

Table 29 shows the amount of soil loss on different plots. Directly comparable results for all plot types exist only for 3 years (1988 to 1990), which is too short a period to calculate statistical values.

The months with the highest erosion risk are July, August and, to a lesser extent, September. The effect of SWC structures is also visible in Table 30: Compared to the control plot, all plots with SWC measures show a significantly lower amount of annual runoff. Level *Fanya Juu* seems to be most effective, but social acceptance is low due to a considerable loss of cultivated area.

Table 29: Comparison of the annual amounts of soil loss [t/ha] at different levels

	1985	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1994**	**1995**	**1996**	**1997**	**1998**
Rainfall [mm]	**397.7**	**425.8**	**384.7**	**582.9**	**258.8**	**244.1**	**321.5**	**533.9**	**658.0**	**552.0**	**575.0**	**558.1**
Erosivity [J/mh]	**154.9**	**201.6**	**302.7**	**491.0**	**89.2**	**159.7**	**210.7**	**346.1**	**448.3**	**510.3**	**363.6**	
MP1, 2 % slope, crops	14.1			33.4	1.9	10.9						
MP2, 10 % slope, crops	27.6	65.8	16.7	44.2	3.9	11						
TP1, 31 % slope, grass	23.5	19.4	38.9	45.1	2.7	7.5		3.6	5.7	9.6	4.6	2.4
TP2, 2 % slope, crops	10.7			61.7	0.4	4.2		9.0	5.1	12.0	6.6	4.9
TP3, 10 % slope, crops	16.6	29.1	18.7	26.7	5.2	6.6	No data	16.3	8.6	24.1	13.4	13.6
TP4, 45 % slope, rocks	16.0	39.7	29.7	17.5	5.1	15.0		7.3	11.6	12.5	9.0	9.4
Control plot (6*30 m)				108.1	2.7	8.6		6.9	84.0	62.6	54.1	62.5
Level double ditch				23.6	0.0	0.2		0.0	5.7	3.3	0.0	1.2
Level *Fanya Juu*				20.1	0.2	0.3		0.0	4.7	1.9	0.0	1.7
Level bund				37.6	0.5	1.5		0.0	19.7	21.9	3.1	2.7

Measurement period for micro plots: 1985 - 1990
Measurement period for test plots 1,3 and 4: 1985 - 1990 and 1994 - 1998
Measurement period for test plot 2: 1985, 1988 - 1990, 1994 - 1998. Two years excluded because total amount of annual runoff exceeded total annual rainfall.
Measurement period for experimental plots: 1988 - 1990 and 1994 - 1998
Measurement period for the river gauge station: 1985 - 1990 and 1994 - 2000
1991 - 1994: Data not available because of war and political changes

Table 30: Comparison of the total annual amounts of runoff [mm] at different levels

Absolute values	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1994**	**1995**	**1996**	**1997**	**1998**
Rainfall [mm]	**397.7**	**425.8**	**384.7**	**582.9**	**258.8**	**244.1**	**321.5**	**533.9**	**658.0**	**552.0**	**575.0**	**558.1**
Erosivity [J/mh]	**154.9**	**201.6**	**302.7**	**491**	**89.2**	**159.7**	**210.7**	**346.1**	**448.3**	**510.3**	**363.6**	
MP 1, 2 % slope, crops	165.2			491.4	43.5	189.8						
MP 2, 10 % slope, crops	114.4	367.4	371.9	379.1	75.9	133.4						
TP 1, 31 % slope, grass	90.1	240.5	188.8	381.4	42.6	80.1		182.8	164.6	209.1	131.6	117.4
TP 2, 2 % slope, crops	43.3			322.5	7.9	45.0	No data	245.6	69.7	272.1	100.2	104.7
TP 3, 10 % slope, crops	40.5	190.4	165.9	305.1	55.5	87.1		283.6	230.5	246.9	166.2	135.5
TP 4, 45 % slope, rocks	40.4	176.7	150.8	184.8	40.5	70.2		183.0	160.4	180.2	180.9	113.6
Control plot (6*30 m)				326.7	31.9	90.8		254.5	248.4	294.7	257.3	251.3
Level double ditch				244.4	5.0	7.7		30.8	108.7	92.6	22.0	58.0
Level *Fanya Juu*				172.5	6.6	8.1		23.2	106.4	70.2	24.7	64.1
Level bund				224.4	9.5	15.7		40.7	148.4	189.0	84.6	90.5

Measurement period for micro plots: 1985 - 1990
Measurement period for test plots 1,3 and 4: 1985 - 1990 and 1994 - 1998
Measurement period for test plot 2: 1985, 1988 - 1990, 1994 - 1998. Two years excluded because total amount of annual runoff exceeded total annual rainfall.
Measurement period for experimental plots: 1988 - 1990 and 1994 - 1998
Measurement period for the river gauge station: 1985 - 1990 and 1994 - 2000
1991 - 1994: Data not available because of war and political changes

The high coefficient of variation (CV) of 0.29 for the annual rainfall at Afdeyu is typical for the highland areas of Eritrea. But not only the high variability of the annual rainfall is important. It is particularly the uncertainty of the beginning of the rainy season and the distribution of rainfall events during the rainy season that makes decisions on which SWC measures to take difficult. This show the limited possibilities of applying annual and mean results. 15 % of the annual rainfall events – for the period between 1985 and 1990 – cause 54 % of the annual runoff and even 70 % of the annual soil loss. This indicates the importance of further investigate single rainfall events for making an effective development of SWC technologies.

Table 31: Comparison of the total annual runoff as percentage of rainfall at different levels in Afdeyu

Runoff as % of rainfall	1985	1986	1987	1988	1989	1990	1991	1994	1995	1996	1997	1998
MP 1, 2 % slope, crops	41.5			84.3	16.8	77.8						
MP 2, 10 % slope, crops	28.8	86.3	96.7	65.0	29.3	54.6						
TP 1, 31 % slope, grass	22.7	56.5	49.1	65.4	16.5	32.8	No data	34.2	25.0	37.9	22.9	21.0
TP 2, 2 % slope, crops	10.9			55.3	3.1	18.4		46.0	10.6	49.3	17.4	18.8
TP 3, 10 % slope, crops	10.2	44.7	43.1	52.3	21.4	35.7		53.1	35.0	44.7	28.9	24.3
TP 4, 45 % slope, rocks	10.2	41.5	39.2	31.7	15.6	28.8		34.3	24.4	32.6	31.5	20.4
Control plot (6*30 m)				56.0	12.3	37.2		47.7	37.8	53.4	44.7	45.0
Level double ditch				41.9	1.9	3.2		5.8	16.5	16.8	3.8	10.4
Level *Fanya Juu*				29.6	2.6	3.3		4.3	16.2	12.7	4.3	11.5
Level bund				38.5	3.7	6.4		7.6	22.6	34.2	14.7	16.2

Soil loss, too, was dominated by few events. High variability and only a small number of heavy storms per year lead to high uncertainty regarding the interpretation of annual values. To better understand erosion processes, single storms must be interpreted. What is clearly visible is that SWC measures help to reduce runoff and store moisture for plant production.

The influence of rainfall erosivity and vegetation cover on soil loss

Table 32 presents the rainfall erosivity classification developed by Herweg & Stillhardt (1999). This classification is based on data of all seven SCRP research stations and a total of 6'091 rainfall events.

Table 32: Classification of rainfall periods by erosivity

Erosivity [J/mh]	Class	Occurrence per year	Average soil loss per event and class [t/ha]	% of annual rainfall periods in the respective erosivity class	% of total annual soil loss caused by all rainfall events in this class during the year
≤ 10	low	frequently every year	0.9	48.1	19.0
> 10 - 20	moderate	frequently every year	1.8	25.3	20.2
>20 - 30	high	several times per year	3.2	10.6	14.8
>30 - 50	very high	more than once in most years	4.8	9.4	20.0
>50 - 100	extreme	once or twice in most years	8.0	5.5	19.5
>100	exceptional	not every year	13.5	1.1	6.6

Crop cover was not systematically analysed in Afdeyu. But the results of all seven SCRP stations show, that under low (0 - 30 %) to moderate (30 - 60 %) plant cover, which is usually found during the onset of rains, storms of all classes can cause erosion. The 100 periods producing the highest soil loss ever measured all occurred under low vegetation cover at the beginning of the cropping season. Under high plant cover (>60 %) only periods of extreme or exceptional erosivity caused a few high soil loss events.

Hydrometric Station Results of the Catchment

The Mayketin hydrological catchment has been surveyed by Robert Burtscher in 2000. According to Burtscher the total size of the catchment is 185.0 ha, but small parts of the catchment drain along the road. This water reaches the river bed below the measurement station and the respective area has therefore to be excluded when calculations are made. The size of the "active" catchment is then 177.2 ha.

Based on the volume of the dam (broken on 07 September 1986 after intensive rainfalls), diverse SCRP measurements (rainfall amount and intensity, evaporation. discharge) and the determination of the water level – discharge - relation by Bosshart (1997), Burtscher (2000) improved the equations to calculate catchment runoff, especially for events with high runoff.

The results presented below are all based on the research results of Burtscher and might differ from the ones presented in Bosshart (1997). The improved equations to determine runoff are the following:

$Y = 0.03 * x^{2.371}$ for $0 < x \leq 42$ cm
$Y = 0.001 * x^{3.28}$ for $42 < x \leq 56.5$ cm
$Y = 0.25 * x^{2.22} - (20 * x - 250)$ for $56.5 < x \leq 190$ cm
(y = flow [l/s], x = water level [m])

When studying the following Figures and Tables one has to have in mind, that samples for calculating sediment load were only collected when water was visually classified as "brown". This results in an underestimation of the total sediment loss of about 10 – 20 % because it needs a certain density of suspended sediments to make the load visible (brown) because for small events no samples were taken.

The catchment discharge for the years 1985 – 1990 is analysed on the basis of automatic river gauge protocols. For the years 1994 – 1998 only the hand taken sample records were available. Compared to the records of the gauging stations the manually taken sample records are about 10 % lower.

Figure 34 and Table 33 present the annual totals of rainfall, catchment runoff and sediment load. It is evident to state that a high total amount of rainfall cause also high runoff and a higher amount of total annual sediment loss. But when the two years of 1994 and 1996 with almost the same amount of rainfall (534 mm and 552 mm respectively) and catchment discharge (113'708 m3 and 122'795 m3 respectively) are compared we see that sediment loss differs remarkably. Explanations con be found only when single events are studied, including rainfall intensity, plant cover density, soil moisture, crop type, area under fallow, time span since last rainfall, etc.

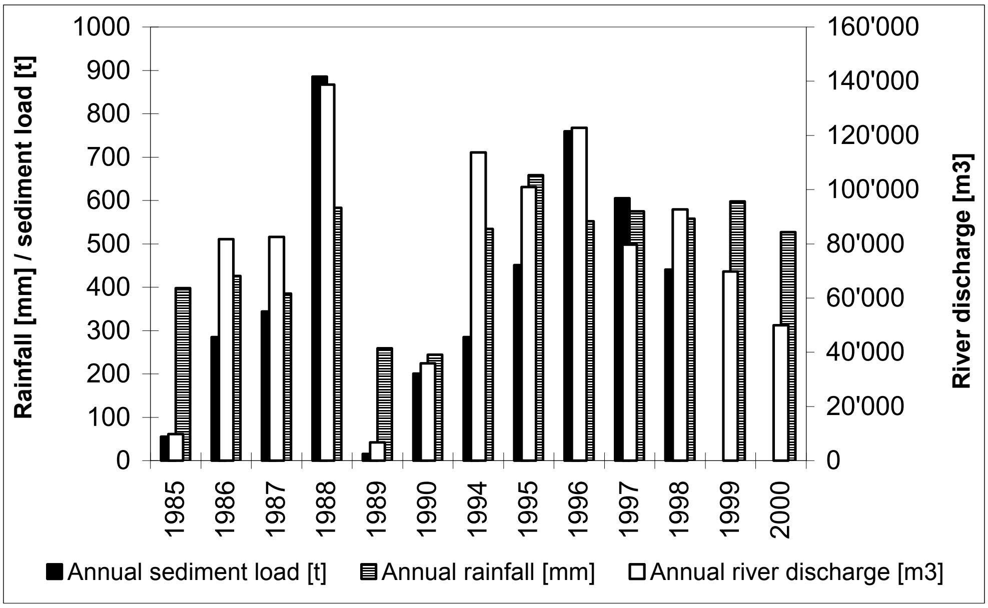


Figure 34: Annual rainfall, river discharge and sediment load for the Mayketin river catchment, Afdeyu, 1984 – 1990 and 1994 – 2000. Data for sediment load in 1999 and 2000 not analysed.

The quality of the relations between rainfall, catchment runoff and sediment load, but also the distribution of the single measurements is shown in Figure 35. The presentation of the parameters follows the increasing correlation coefficient. Basis of this figures are not monthly or annual totals, but values measured during single events and sample size is around 500.

Table 33: Mean annual values of the most relevant hydrological parameters, Mayketin river catchment, Afdeyu

Year	Total annual rainfall [mm]	Annual river discharge [m^3]	Mean annual drainage ratio [%]	Total annual sediment load [t]	Mean annual sediment concentration [g/l]
1985	398	9798		55.26	5.64
1986	426	81671	10.37	284.84	3.49
1987	385	82534	11.60	343.77	4.17
1988	583	138751	12.87	885.77	6.38
1989	259	6696	1.40	15.22	2.27
1990	244	35851	7.94	200.40	5.59
1994	534	113708	11.51	285.15	2.51
1995	658	101006	8.30	450.71	4.46
1996	552	122795	12.02	759.07	6.18
1997	575	79734	7.50	605.32	7.59
1998	558	92649	8.97	440.81	4.76
1999	598	69748			
2000	527	49953			

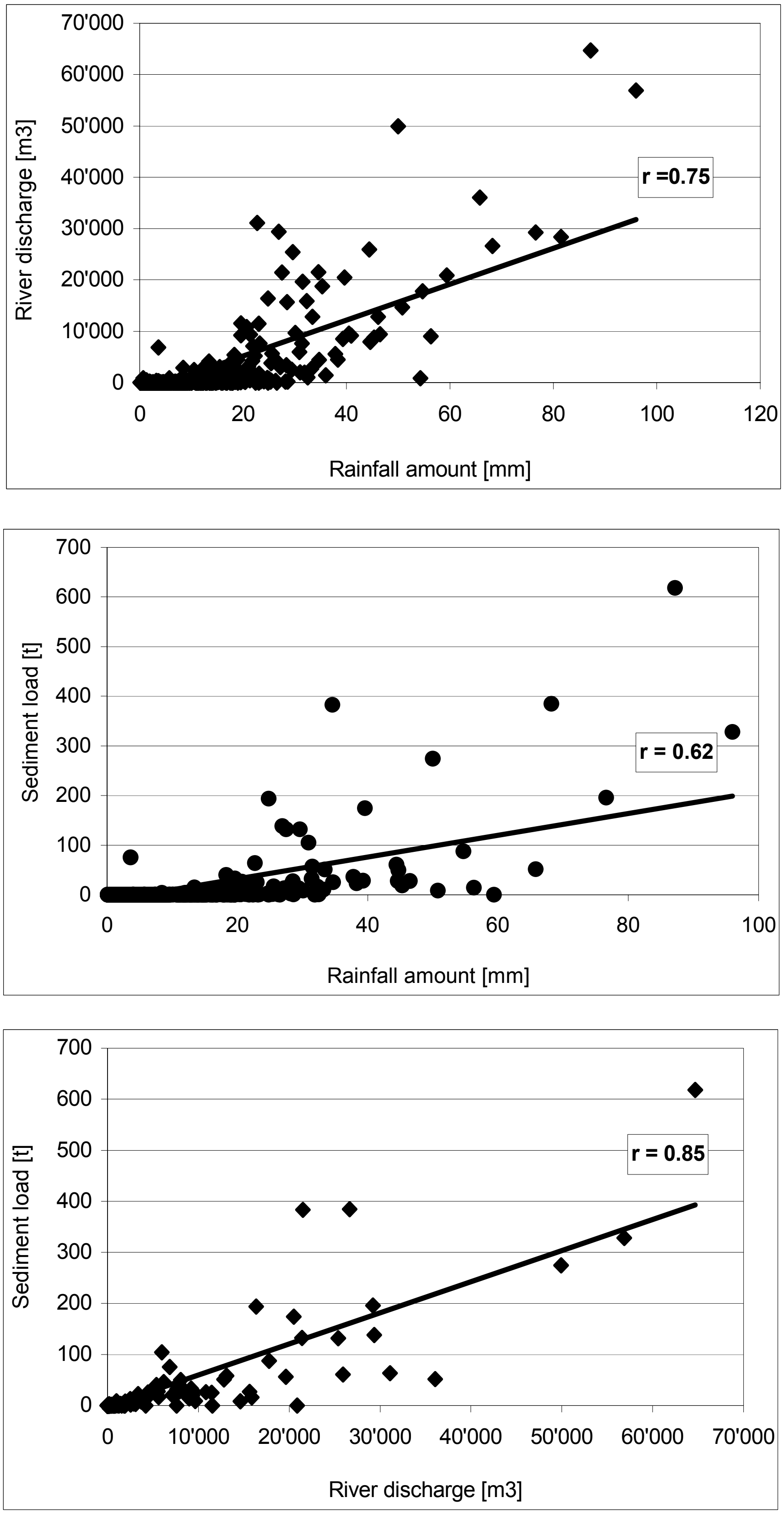


Figure 35: Relation and correlation of rainfall, catchment runoff and sediment load for single events (1985 - 1990 and 1994 - 2000).

Mean monthly values are given in Table 34 and Figure 36. It can be seen that during the small rainfall season in spring when soils are dry and freshly ploughed, a smaller percentage of the rainfall leaves the catchment compared to the situation in August, when the total amount of rainfall is high and soil moisture content is higher than in spring.

Table 34: Mean monthly values of the most relevant hydrological parameters, Mayketin river catchment, Afdeyu

Month	**Mean monthly rainfall [mm]**	**Mean monthly river discharge [m³]**	**Mean monthly drainage ratio [%]**	**Mean monthly sediment load [t]**	**Mean monthly sediment concentration [g/l]**
January	**17.3**	**0.0**	**0.00**	**0.00**	**0.00**
February	**8.2**	**0.0**	**0.00**	**0.00**	**0.00**
March	**10.5**	**0.0**	**0.00**	**0.00**	**0.00**
April	**28.8**	**1677.2**	**3.71**	**39.07**	**11.65**
May	**49.5**	**3779.2**	**4.11**	**53.99**	**11.43**
June	**23.3**	**994.3**	**2.06**	**12.69**	**8.94**
July	**117.7**	**14261.6**	**7.39**	**124.83**	**7.96**
August	**160.5**	**40734.2**	**14.81**	**176.60**	**3.94**
September	**65.4**	**13207.4**	**11.84**	**38.63**	**2.66**
October	**29.0**	**4242.2**	**7.96**	**39.96**	**4.28**
November	**23.9**	**492.6**	**1.16**	**3.26**	**3.31**
December	**1.8**	**0.0**	**0.00**	**0.00**	**0.00**

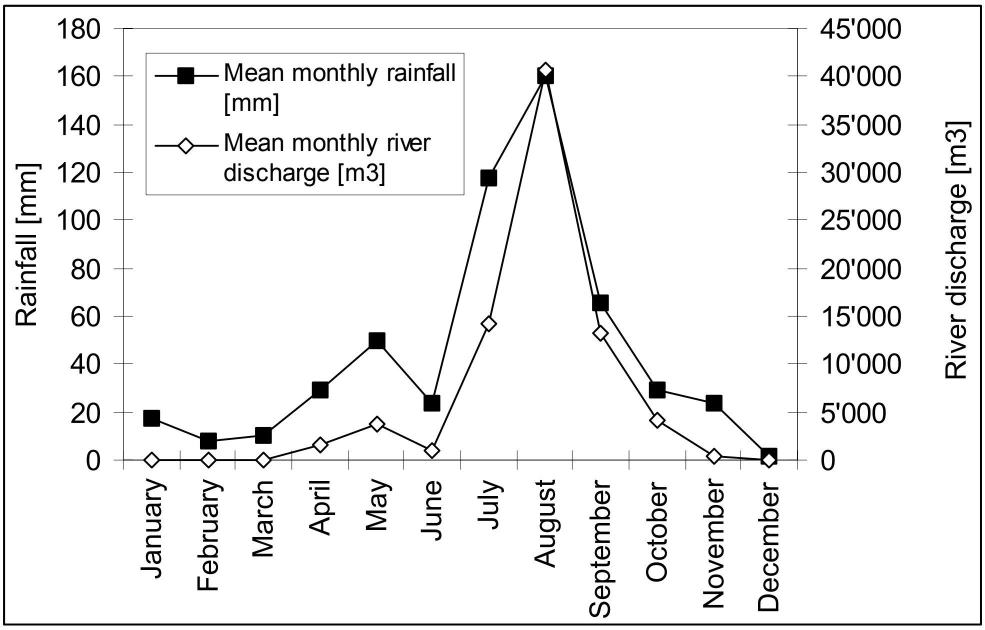


Figure 36: Mean monthly rainfall and mean monthly river discharge. Mayketin river catchment, Afdeyu, 1985 - 1990 and 1994 - 2000

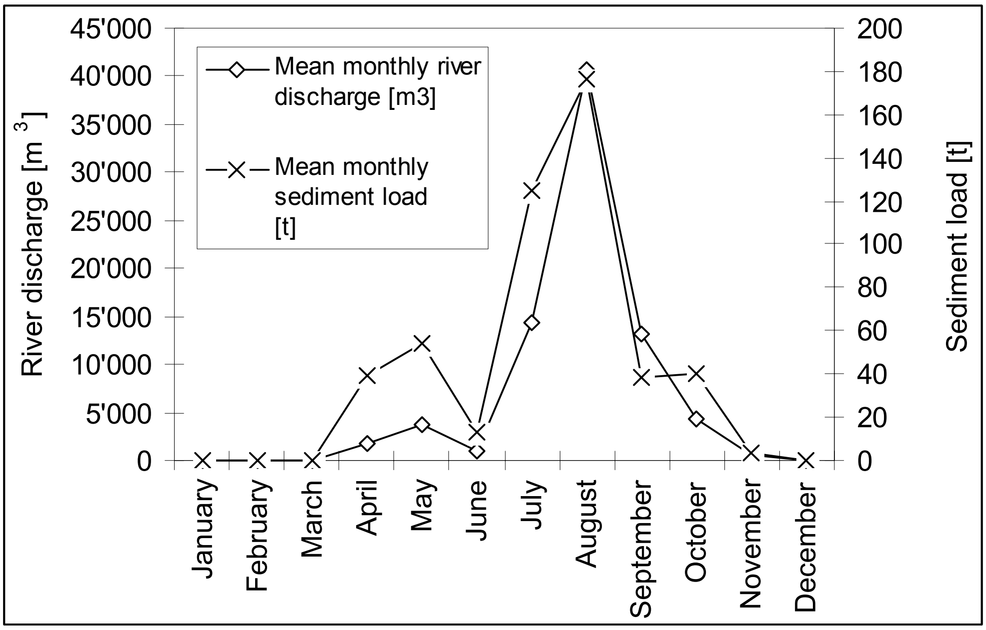


Figure 37: Mean monthly river discharge and mean monthly sediment load. Mayketin river catchment, Afdeyu, 1985 - 1990 and 1994 - 1998

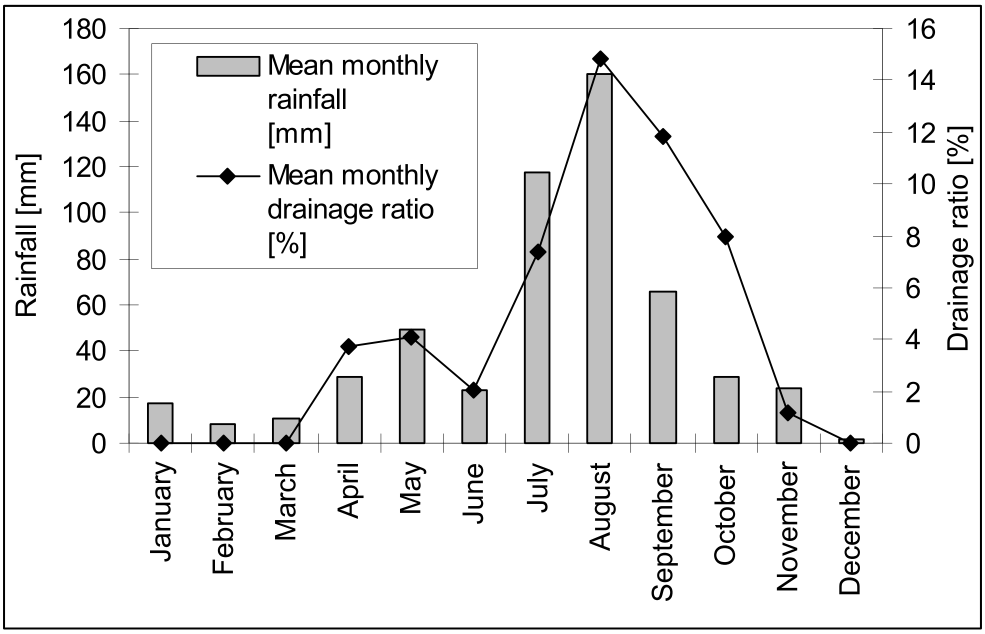


Figure 38: Mean monthly rainfall and mean monthly drainage ratio, Mayketin river catchment, Afdeyu, 1985 - 1990 and 1994 - 2000

The discharge expressed as percentage of water leaving the catchment after a rainfall event is known as drainage ratio. For single events the variability is very high, again because numerous other factors influence the catchment runoff (see above). In addition to the analysed data Burtscher (2001) calculated the annual values of 1999 and 2000, compared it to selected years and concluded tat the micro basins installed in 1998 reduced the drainage ratio remarkably.

A comparison of the mean monthly sediment concentration (gram sediment per litre runoff) with the drainage ratio shows, that in the beginning of the rainfall season, when soils are freshly ploughed and plant cover is weak, sediment concentration is high and discharge ratio low (high water demand of dry soils, generally low rainfall intensity). For the main rainfall season the picture of drainage ratio follows the picture of the rainfall amounts, but with increasing plant density the sediment concentration decreases (see Figure 39).

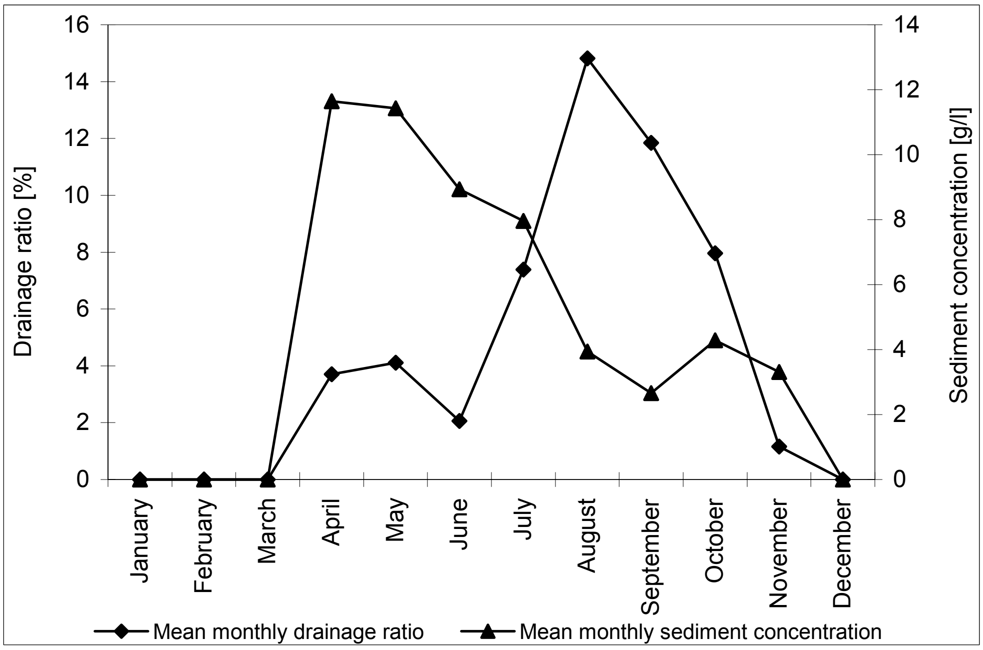


Figure 39: Mean monthly sediment concentration and mean monthly drainage ratio, Afdeyu, 1985 - 1990 and 1994 - 1998

Further reading

Research Reports:

Berhanu Fentaw. 1991b / Burtscher, R. 2000 / Burtscher, R. 2001 / Hänggi, F. 1997 / Herweg, K. and Ludi, E. 1999 / Herweg, K. and Ostrowski, M.W. 1997 / Herweg, K. and Stillhardt B. 1999 / Ludi, E. 1997 / Million Alemayehu. 1992 / Tsehai Berhane-Selassie. 1994 / Werner, C. 1986

Theses:

Kefeni Kejela. 1987 / Semere Zaid Ghebremhedin. 1998 / Yeneabat W. Hanna. 1984 / Werner, C. 1985

Social and Economic data

Demography

The only available data about the population of the village of Afdeyu are found in a land use planning report compiled for the TOKER Land husbandry project (quoted in Dawod et al 1999):

Table 35: Demographic data of Afdeyu

Total number of households	326
Total number of female-headed households	80
Total number of women	370
Total number of men	483
Total number of children	350
Total population in Afdeyu	1203
Average household size	3.7 persons
Number of people per ha cultivated land	8

Interpretation of these data is difficult. Basic results cannot be reconciled with demographic data from other areas of Eritrea and should be verified by follow up studies. This becomes immediately clear from a look at the following figures derived from Table 35 (Table 36):

Table 36: Additional demographic data calculated from basics in Table 35

Total number of man-headed households	246
Total number of men living in man-headed households*	483
Mean number of men per man-headed household	2.0
Total number of female-headed households	80
Maximal number of women living in man-headed households**	290
Maximal number of women per man-headed household	1.2
Mean number of children per household***	1.1

Remarks:

- Different sources (e.g. Frey et al 1997, Tronvoll, 1996) state that households are only female-headed if no adult man lives in the household. For example, if a widows son grows up he then is automatically the household head.

** This is an estimation on the basis of total women minus one woman per female-headed household. It is the maximal number of women living in man headed households

*** Under the assumption that there is no difference between the number of children in female-headed households and man-headed households.

The comparison of the figures presented in Table 36 with figures from other regions in Eritrea shows the following:

- In rural areas, more than half of the total population are normally children. A study recently done in Adi Behnuna (Zoba Debub) shows that between 52 and 55 % of the total population are younger than 15 years. In Afdeyu, only 29.1 % are children. How can this very small number of children be explained?
- The total number of men living in Afdeyu (483) is much higher than the total number of women (370). Expressed in percentage, 40.2 % of the total population are male and only 30.7 % female. Temporal or permanent migration is much more frequent with men than with women in other regions of Eritrea. How comes that population dynamics in Afdeyu have developped so differently from other regions?

Wealth Ranking

Table 37: Results of a wealth ranking (Dawod et al 1999)

	Category 1	Category 2	Category 3
Number of households in the respective category	11	20	35
% of households in the respective category	17	30	53
Indicators used by the informants to allocate a household to a certain category	two oxen, enough labourer also for off-farm income	one ox, maybe one donkey no off farm income	no oxen dependent on relatives

Provided that the sample of 66 households used for the ranking is representative, it is easy to conclude that oxen are one of the most important factors in the categorisation of households according to wealth. It also seems that the number of oxen is highly correlated with the total amount of human labour force at household level. Families ranked in category 1 seem to have the capacity to send someone to generate off-farm income, families ranked in category 3 do not have this capacity. It would be interesting to compare family size and family structure of the different wealth categories in greater detail through a follow up study.

Water

Two new and properly maintained wells provide enough clear drinking water for the whole population. Walking time from the village to the wells is about ¼ to ½ hour. Water transport is either by donkeys (with girbas) or in Jerry cans on women's backs.

Also animals are watered there. Fencing around the well hinders animals from entering the area reserved for fetching drinking water, and the entrance can be locked if necessary. A guard is responsible for the management of the well. He is paid by the villagers.

It is not allowed to take irrigation water from the same wells. For this water people have to dig holes along the riverbed.

Infrastructure

The only source of electricity is a generator belonging to the church. It is exclusively used to illuminate the church. All households have to contribute by buying fuel.

Fife small shops in Afdeyu offer the most basic goods such as tea, coffee, sugar, bread and cigarettes.

The nearest primary school is in Tsehaflam, about 1 km from Afdeyu. The capacity of the school building as well as the number of teachers, is too small nowadays. Not every child has the opportunity to attend school, but people reported that gender preference does not influence attendance. The oldest child of every household is selected first.

The number of children attending school (as given in Table 38) is the total of at least two villages. Therefore, it is not possible to estimate what percentage of children from Afdeyu attend classes. Drop out rate during the school year is about 7 % with boys and 1.7 % with girls. The statistics do not specify how many children drop out in which grade.

Table 38: Number of students attending the school in Tsehaflam in 1998/99 (Dawod et al 1999)

Grade	number of boys	number of girls	percentage of girls
1	55	48	46.6 %
2	54	51	48.6 %
3	42	47	52.8 %
4	53	58	52.3 %
5	64	35	35.4 %

Up to grade 4, the balance between boys and girls attending the school is quite even. But only 35 % of all pupils in grade 5 are girls. It would be interesting to understand why this imbalance arises suddenly from one year to the other.

Serejeka, the local centre, is about 2 km SE of Afdeyu and can be reached on an earth road. Serejeka is on the main road Asmara - Keren, about 20 km north of Asmara. Once a day, a bus connects Afdeyu with Serejeka. Sometimes during heavy rains, the earth road is flooded for a short time. A second road connects Afdeyu with the eastern lowlands. Across the escarpment, this road is very steep and difficult to drive on during the rainy season.

Public services offered in Serejeka are: a mill, a health centre including an ambulance, primary school, junior school, secondary school (was under construction in 1999). Friday is market day.

Women's Situation

All women in the village are members of the National Union of Eritrean Women. The monthly contribution is about 50 cents.

The women's work includes household management, food preparation, looking after children, washing etc. Other daily tasks are fetching water and searching firewood. Moreover, women help in most of the field work like weeding, harvesting and threshing. They go to markets and carry cereals to the mill. Pregnant women continue to work fully until the last day of pregnancy, and they resume their duties a few days after giving birth.

Two trained midwifes live in Afdeyu. Against a small fee they help women give birth. Up to now, most families have not made use of this service, but have had older relatives attending the pregnant woman.

Most of the female-headed households consist of widows. After the husband dies, half the family land goes back to the community. Because women are traditionally not allowed to plough, they depend on relatives or other farmers, which means that they have to pay half the harvest to the farmer ploughing their fields.

Land Use and Land Tenure

Fife areas are differentiated in Afdeyu: Ghedena, Aguari'e, Grat Hamushte, Sinihabera, Kelkel. It is not clear whether this classification is made on the basis of geographical or topographical criteria or whether it depends on soil properties. However, all households own land in all categories. Ghedena is around the village and in the flat alluvial plain around the wells, where about ten households irrigate a small plot of land (about 50 m^2). Main products grown on these plots are potato, onion and tomato. The other four categories are under crop rotation. One area is always under fallow (kadra).

Fertilising is too expensive for most farmers so that only the richest can afford it. The TOKER land husbandry project has twice offered fertiliser on a loan basis

Parts of the area belonging to Afdeyu have been used to build the new town of Serejeka. The pressure on the remaining land is high, with a mean size of about 1/8 ha of arable land per household. In a campaign, some years ago, part of Kelkel was planted with eucalyptus trees which aggravated the high pressure on the scarce land reserves.

Soil conservation structures are mainly built to harvest water. Stone and soil bunds were implemented by a food-for-work programme, followed by the construction of tide ridges, during a cash-for-work programme in 1999. The tide ridges have not been accepted by farmers because the area lost through conservation structures is too big and water logging frequently happens. In woodland areas, half moons and small basins between the tide ridges (also constructed during the cash-for-work programme) are additional measures used to conserve water.

Livestock Holding

Table 39: Number of livestock in Afdeyu (Dawod et al 1999)

	Total number	number per household
Oxen	200	0.61
Cows	70	0.21
Camels	no data	no data
Horses	no data	no data
Mules	no data	no data
Donkeys	100	0.31
Sheep and goats	270	0.83
Poultry	400	1.23

The above figures are estimates given by village representatives. It seems that at least the number of cows was underestimated. Ploughing, threshing and livestock breeding are very difficult with such a small amount of cattle. Cross checking with the results of the wealth ranking showed that the total number of oxen is more credible.

The grazing area within the community of Afdeyu is very small. However, grass for cattle can be cut in the afforestations. Moreover, for part of the year the animals migrate to Bahri on the eastern escarpment and to range-land areas near Akordet in the western lowlands.

Further reading

Theses:
Michael Kidane Mebrahtu, 1997 / Semere Zaid Ghebremedhin, 1998

Other publications
Landon, J.R., (editor) 1991 / Virginia Dawod, Semere Zaid, Lula Tekle, 1999

Workshop on Long Term Monitoring of Afdeyu

(01 /02 November 2001 in Asmara)

In Afdeyu research station, data and information with respect to soil erosion, soil and water conservation and related parameters were collected since 1984. The central questions raised in recent years were: Should research in Afdeyu continue? What type of research should be conducted in future? How the present research set-up can be improved? And whether there is a need to have a network of similar research stations in different agro-climatic zones of Eritrea? Basically, these questions must be answered by concerned Eritrean institutions. This, however, requires that available information be analysed first and possible interpretations be offered. The Afdeyu workshop was, therefore, intended to present all available data in a summarised form, discuss the findings and draw necessary conclusions. The workshop was organised through the Ministry of Agriculture, workshop co-ordination and presentations were within the responsibility of CDE.

Workshop programme 01 November 2001

Schedule	Topic	Time
9.00 – 9.30	Welcome note, programme Justification, goals and expected outputs of the workshop Introduction of participants	30 Min
9.30 – 10.30	Presentation and discussion of research concept and methodology	60 Min
10.30 – 11.00	Coffee break	30 Min
11.00 – 12.00	Presentation and discussion of climatic data and soil data	60 Min
12.00	Official workshop photo	Some minutes
12.15 – 14.00	Lunch	Almost two hours
14.00 – 15.30	Presentation and discussion of soil and water conservation results	90 Min
15.30 – 16.00	Coffee break	30 Min
16.00 – 17.00	Presentation and discussion of land use data and socio economic data	60 Min
17.00	Closing of first day	

Workshop programme 02 November 2001

Schedule	Topic	Time
8.00 – 12.00	Field trip to Afdeyu	4 Hours
12.00 – 14.00	Lunch in Asmara	2 Hours
14.00 – 15.30	Group work, presentation and discussion on lessons learnt	90 Min
15.30 – 16.00	Coffee break	30 Min
16.00 – 17.00	Plenary session on SWC research needs, how to realise them (responsibilities, commitments). Recommendations and next steps.	60 Min
17.00	Closing of Workshop	

Goal of the Workshop

Relevant and need-oriented soil and water conservation (SWC) research in Afdeyu (continuation of Afdeyu as research site with improved, praxis-relevant research set up, oriented towards local needs).

Expected Outputs

- Awareness, common background and understanding of the Afdeyu research approach and available SWC data
- Lessons learnt – what can be concluded and what are future research needs in SWC (vision)
- Suggestions how to realise the vision (commitments, responsibilities, activities)
- Recommendations and next steps concerning SWC research in Afdeyu

Procedure

1. Presentation and discussion of research approach and results
2. Field trip to Afdeyu reflecting the presentations
3. Group work on "lessons learnt"
4. Plenary discussion on research needs, vision of stakeholders, recommendations, next steps, etc.

List of Lessons Learnt, including Research Needs (Visions) and Recommendations

The following list reflects the lessons learnt from the point of view of participants of different background, as well as the experience of CDE, which has been involved in Afdeyu since 1984. At the same time the lessons learnt regarding research topics and contents indicate the visions of the groups with respect to future research needs. The lessons learnt regarding the methodology are related to those of future research topics. Administrative and organisational lessons learnt reflect the groups recommendations and views on which steps are necessary to realise the visions.

Research topic / content and research needs (visions)	**Methodology (future research topics)**	**Administration / organisation (recommendations)**
First of all be clear about research needs (research questions)	Improve efficiency of the equipment in the station	Data management must be ensured from collection to publication
Soil and water conservation must be site specific and household-specific	Bench mark data should be taken Holistic approach should be followed (Livestock, People, Etc) System approach should be used	Data analysis and communication should be improved
Consider ecological (economic) aspects, viability and (social) adaptability	Participatory approach	Collaboration
Does on-site soil and water conservation affect the volume of the dam	Build up on indigenous Knowledge	Research responsibility is connected to the research division of the MoA Link with other national research stations should be strengthen
Consider possible competition of crop land and grazing land	Inter- & transdisciplinary approach needed	Research should be applicable (communication gap should be solved)
Socio-economic studies are necessary	Site selection was based on the actual political situation Small catchment Collect baseline data before starting in-depth studies Study the effect of SWC measures introduced through the Ministry of Agriculture	Responsibility for research must be in the country

Research topic / content and research needs (visions)	**Methodology (future research topics)**	**Administration / organisation (recommendations)**
Effect of conservation measures on yield	Change of experiment/test plots	Communication between research station, extension service, decision-makers, etc must be improved
Research questions should be obtained from discussions with farmers Farmers have to be asked for solutions also (inventory of used / traditional SWC methods).	Soil texture analysis should be included	Research and extension link
Development oriented research	High climatic variation requires long term monitoring	Continuity of employment is important
Tools to improve the link between research findings and indigenous knowledge	Soil analysis has to be done (e.g. Nutrients, Texture)	One research station can not be representative for all agro-ecological zones in Eritrea
Research on agronomic measures on catchment level	For new sites detailed initial soil survey has to be done.	Consider research findings before implementing policies & technologies
Effect of biological measures on conservation	Methodological difficulties to carry out research in inhomogeneous study areas	Build up stations in other agro-ecological zones.
Focus of research was on physical soil conservation measures in the past. Future research must include biological conservation	Effects of different crops on nutrient status should be studied	Such stations should be established in the different agro-ecological zones
Watershed approach required	Upgrading the equipments	People should be allocated to take responsibility
Topics to be included in future research: Agro forestry Production topics Effect of biologic SWC measures Nutrient leaching Indigenous soil and water conservation		Monitoring and supervision of the station must be guaranteed
Changes of soil and runoff under different land use practices		People who work in the research should be upgraded (capacity building)
Effect of conservation measures on fertility status of the soil		

Commitments

The Ministry of Agriculture (DARHRD) is the leading agency and responsible for the continuation of SWC research in Afdeyu and possible similar stations in other agro-climatic zones of Eritrea. DARHRD is willing to cooperate with interested institutions, such as CAAS and CDE.

Supposed that basic operation and supervision of Afdeyu is guaranteed by DARHRD, CDE's commitments are:

- Re-construction of office and living quarters in Afdeyu
- Training of research assistants in basic data processing and presentation
- Support basic data collection (long term monitoring), for the time being:
  - Climatic data
  - River data
  - Land use and productivity data
- Backstopping of CDE's interdisciplinary team, on conceptual and methodological aspects, experiments, data analysis, etc.
- Support of Eritrean research in SWC by a permanent consultant (as of 2003)

Workshop participants

Figure 40: Workshop participants, 1st of November 2001, Asmara, Eritrea

Name	**Organisation / institution**	**Position**
A,J,Thomas	Ministry of Agriculture	Core expert (surface & ground grader)
Abdulkadir M.Dawod	CAAS, University of Asmara	Dean
Abrham Mehari	University of Asmara	Lecturer & researcher on management of irrigation systems
Ariam Tekeste	University of Asmara	Lecturer on soil and water conservation
Asmerom Kidane	Ministry of Agriculture	Director of research
Belay Habtegabir	Ministry of Agriculture	Irrigation engineer
Bereket Tsehaye	University of Asmara	Senior student
Berhane Mogos	Ministry of Agriculture	Planning and statistics
Bissrat Ghebru	CAAS, University of Asmara	Instructor
Bokretsion Habte	Ministry of Agriculture	Agronomist
Daniel Medhanie	Ministry of Agriculture	Research assistant
Dr. R.S. Saini	Ministry of Agriculture/FAO	Mission leader SSC
Drar Tesfamichael	Ministry of Agriculture/DARHRD	Unit Head
Ermias Asmelash	Ministry of Agriculture/AEAS	Horticulture
Estifanos Bein	Ministry of Agriculture	Forestry & W.L
Eyob Habte	Ministry of Agriculture	Provisional head of SWC research
Hadgu Ghebreendrias	Ministry of Agriculture, land resources and crop production department	Forest expert
Kiflemariam Abraha	Ministry of Agriculture, research and HRRD department	Soil research
Letezhi Kibreab	Toker Project	Forestry
Mebrahtu Iyassu	Ministry of Agriculture	Director General
Mehretab Tesfai	CAAS, University of Asmara	Lecturer on soil and water management
Mengistu Russom	Ministry of Agriculture	Rangeland management specialist
Michael Kahsai	CAAS, University of Asmara	Instructor in veterinary medicine, Workshop-facilitator
Mogos W.Yohannis	Ministry of Agriculture	Irrigation engineer
Nezehty Abbay	DARHRD	Forestry
Okbit Bahta	Toker Project	Horticulture
Samuel Asgedom	University of Asmara	Horticulture
Semere Amlesom	Ministry of Agriculture, DARHRD	Director General of DARHRD
Semere Asmelash	Ministry of Agriculture	Research assistant
Semere Zaid	University of Asmara	Soil and water conservation
Somaya Julu		
Tedros Ghebreab	Ministry of Information	Reporter to E.N.A

Name	Organisation / institution	Position
Tseggai Gherezgiher	Vision Eritrea	Liaison
Weredeyesus Tsegai	Ministry of Agriculture	Agro meteorologist
Woldeselasie Ogbazghi	University of Asmara	Assistant professor
Zufan Mekama	Ministry of Agriculture	Animal nutrition. Laboratory
Karl Herweg	CDE	Co-ordinator sustainable land management
Brigitta Stillhardt	CDE	Workshop co-ordination and data management Afdeyu
Robert Burtscher	CDE	Instructor of GIS/RS

Abbreviations:

AEAS	Association of Eritreans in Agricultural Sciences
CAAS	College of Agriculture and Aquatic Sciences
CDE	Centre for Development and Environment
DARHRD	Department of Agricultural Research and Human Resource Development
E.N.A.	Eritrean News Agency
FAO	United Nations Food and Agriculture Organisation
GIS	Geographic Information System
HRRD	Human Resources and Rural Development
SWC	Soil and Water Conservation

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Annex

Land use 1994 - 1998

Legend:

bl	Barley
bn	Bean
fa	Fallow
hb	Haricot bean
ho	Horse bean
li	Linseed
mz	Maize
on	Onion
po	Potato
te	Teff
wt	Wheat

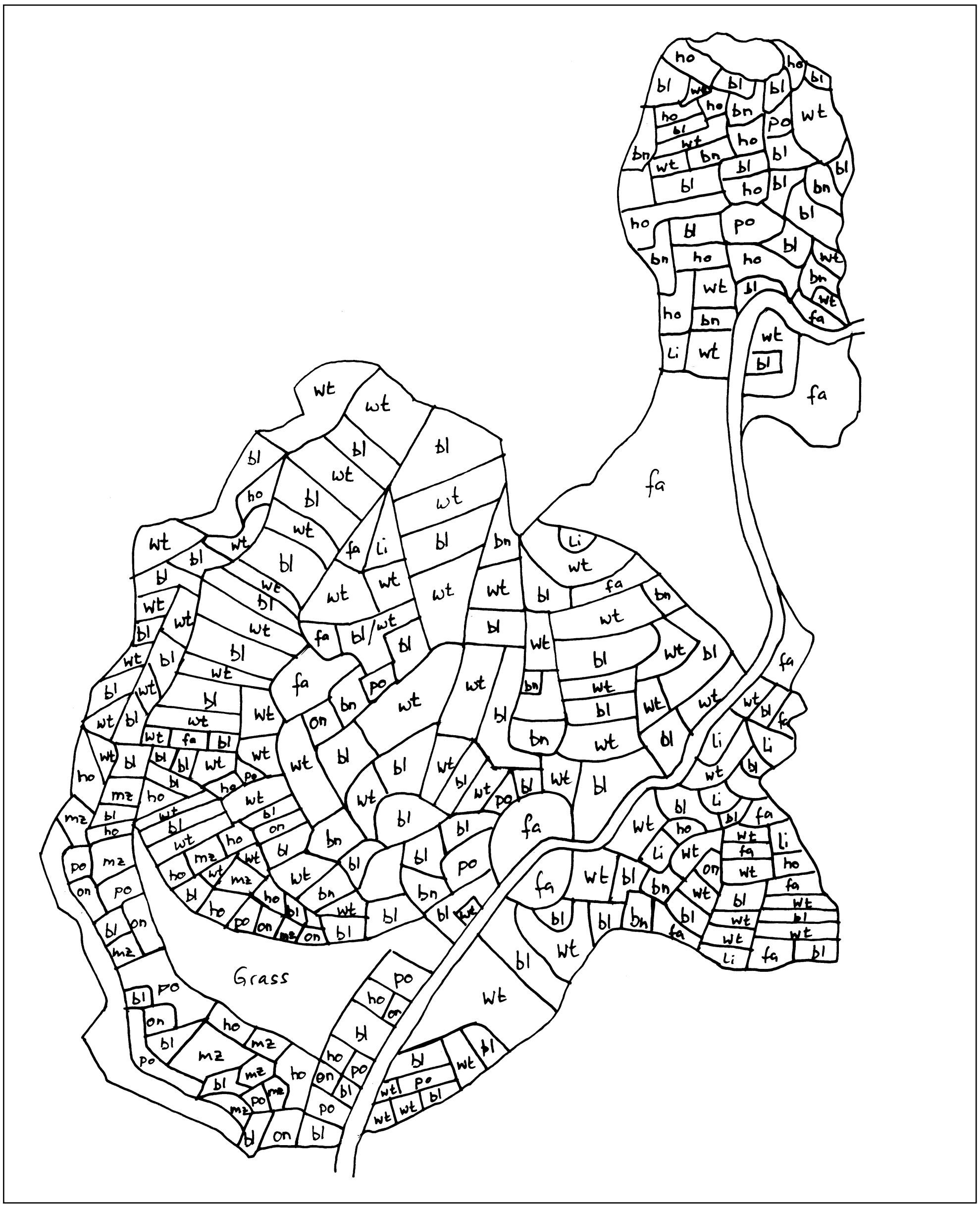

Figure 41: Catchment land use in Afdeyu in 1994

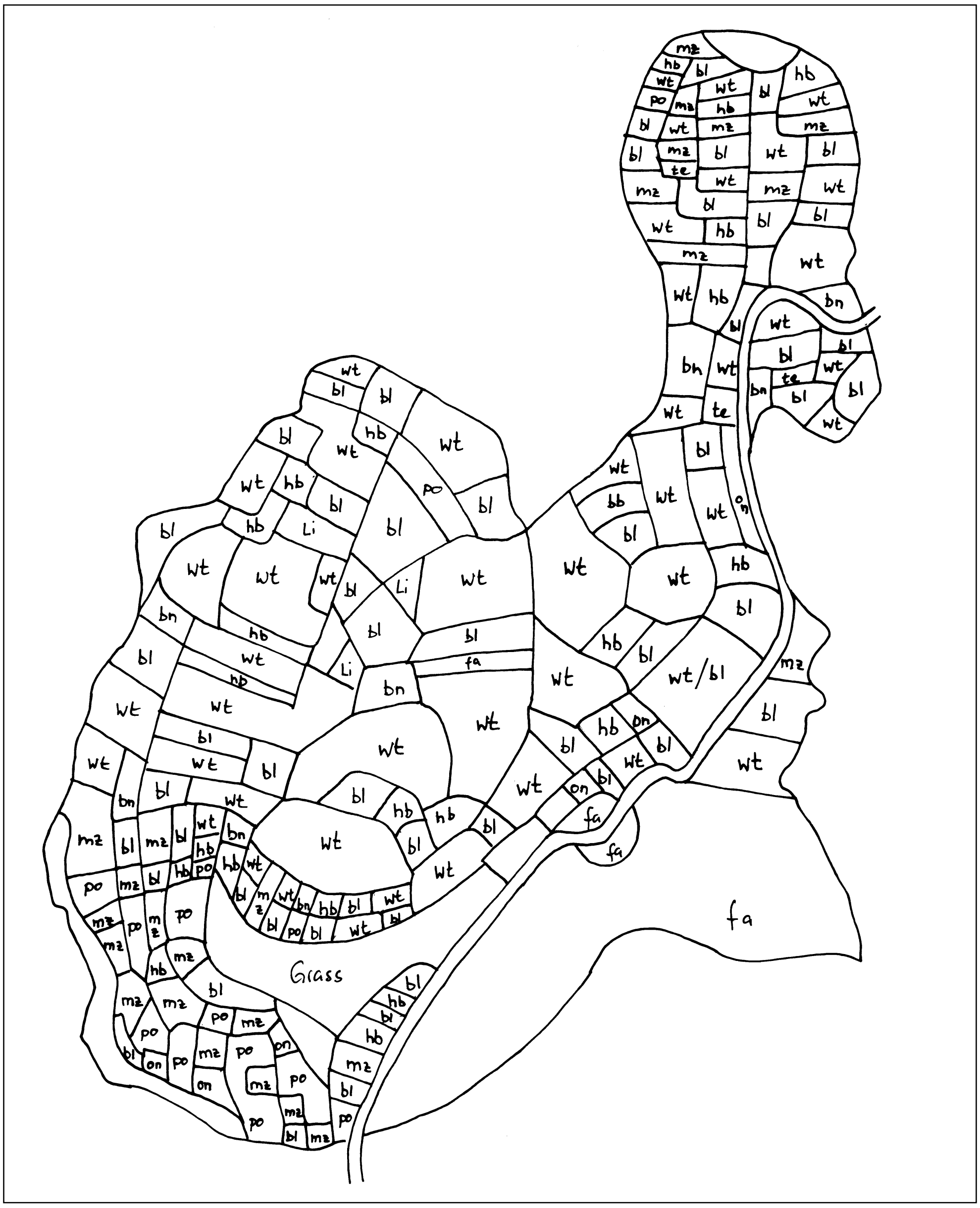

Figure 42: Catchment land use in Afdeyu in 1995

Figure 43: Catchment land use in Afdeyu in 1996

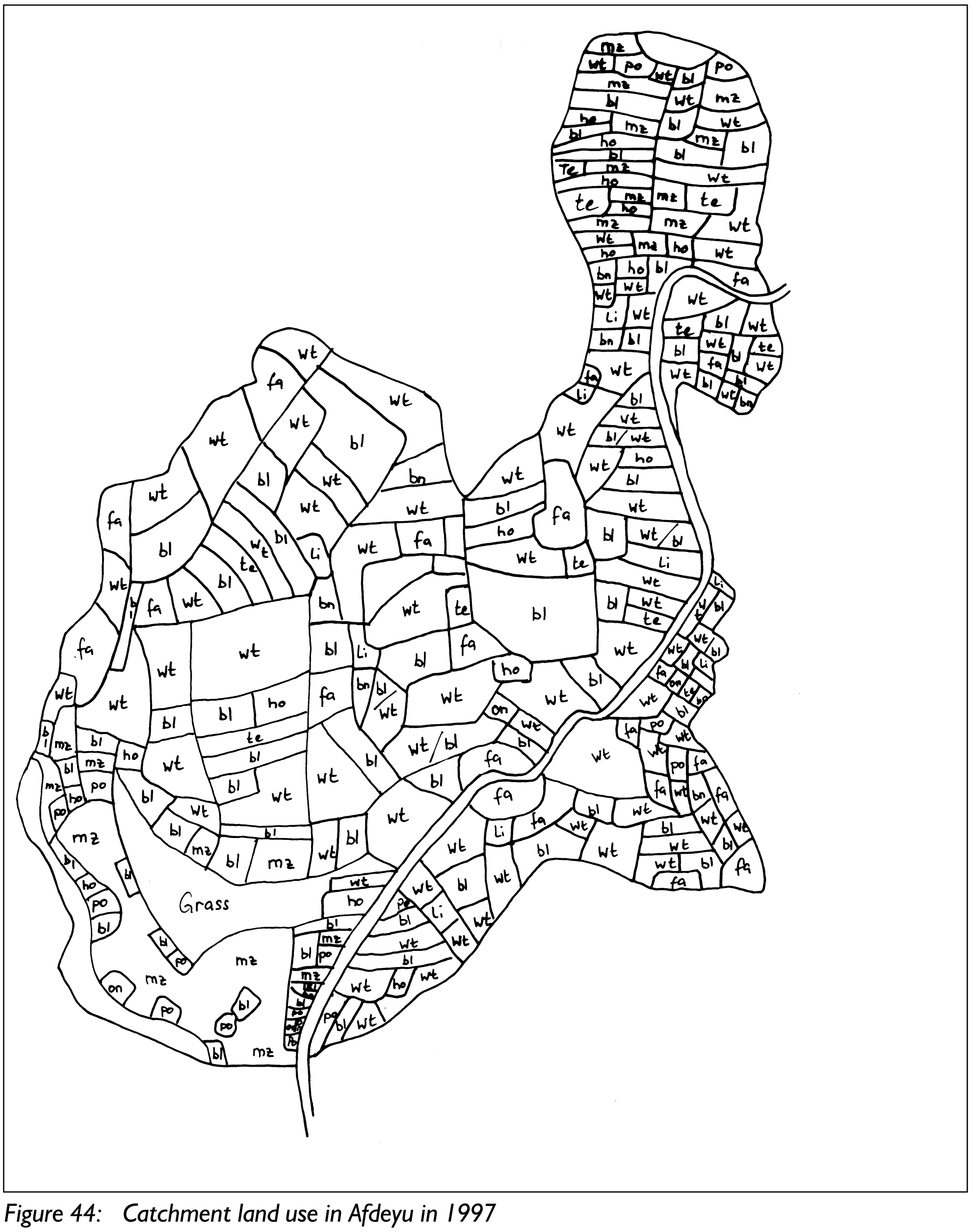

Figure 44: Catchment land use in Afdeyu in 1997

Figure 45: Catchment land use in Afdeyu in 1998

Ikonos satellite image with digital elevation model

Figure 46: Ikonos satellite image